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Master of Science

By

Nelson L. Smith, Capt, USAF

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APPROVED FOR THE DEPARTMENT OF METEOROLOGY

Peter F. Lester

Francis L. Ludwig

Marcellus W. Burton

APPROVED FOR THE UNIVERSITY

ABSTRACT

A SMALL COMPUTER EXPERT SYSTEM FOR LOW-LEVEL TURBULENCE FORECASTS AT FORT IRWIN, CALIFORNIA

by Nelson L. Smith

This thesis addresses the need for comprehensive, accurate Low Level Turbulence (LLT) forecasts at the US Army's National Training Center (NTC), Ft Irwin, California. A LLT forecast expert system was developed for use on a small computer. The program initially derives a single macroscale turbulence index from observations of current atmospheric lapse rate, pressure tendency, wind speed, and terrain roughness for NTC. Subsequently, a field of values for a Local Scale Turbulence Index (LTI) is computed as a function of macroscale index, local terrain roughness at 1 km intervals, and winds generated from local observations and a mass consistent wind model. LTI is modified for terrain wake effects and Pilot Reports (PIREPS) of turbulence in the area. Threshold LTI values representing turbulence categories are graphically displayed on the computer terminal, superimposed on terrain contours. Current PIREPS are also displayed. Verification data indicate the model is a useful operational tool.

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The author would like to express his deepest appreciation to the following people: Mr Frank Hansen and Ms Pam Tabor, US Army Atmospheric Science Laboratory, for their technical support in providing Ft Irwin terrain data and the LTIGRAPH and PLOT computer routines; Mr John Marrs, Science Advisor at Ft Irwin, for sharing his intimate knowledge of the flying conditions at Ft Irwin; Mr Francis Ludwig and Dr Alison Bridger for their assistance with the WOCSS model; 2Lt Bryan Logie, USAF, and 2Lt Jon Incerpi, USAF, for their assistance in data reduction; Mrs Donna Hurth and Mr Jeff Baldwin for their dedicated technical support; special thanks to Christopher and Jaqueline Emery for their love and support through very trying times; and, finally, to Dr Peter Lester and Mr Marcellus Burton, without whose friendship, support, and technical expertise this project would not have been possible.

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1. Introduction

1.1 Problem Definition

The impact of turbulence on aircraft operations remains one of the most serious problems in aviation today. Turbulence accounts for 24% of large commercial carrier accidents, and 54% of all weather-related accidents (McLean, 1986). It follows that there is an ongoing need for accurate forecasting of turbulence at all levels in the atmosphere, not only for commercial and military aviation (Chandler, 1986; Miller, 1986) but also for the launch and recovery of space vehicles such as the space shuttle (Kolczynski et al., 1986; Endlich, 1989).

Low level turbulence (LLT), which can be defined simply as bumpiness in flight through the planetary boundary layer (PBL), is more commonly encountered than any of the other turbulence types, not only because all flights must pass through the PBL, but because the surface is a source of turbulent eddies, and the primary response scales of aircraft are in the size range of those eddies. As with CAT, cases of severe LLT (i.e., resulting in a momentary loss of control of the aircraft) are infrequent, however the proximity of the ground allows less room for recovery, making LLT a more serious hazard than turbulence at higher levels. Thus accurate prediction is a high priority.

Despite this need, current LLT forecasting methods, especially for dry convection and mechanical turbulence, are crude and subjective at best. McLean (1986) has pointed out that although the physical causes of LLT are generally well understood, forecast errors still result from several causes, including differences in scale between observations and forecast parameters, initial values which themselves must be estimated, limited data for verification, differing levels of forecaster experience, and subjective forecast terminology. These problems are exacerbated in the presence of complex terrain.

An example of a specific LLT forecast problem is found at the US Army National Training Center (NTC) at Ft Irwin, CA. NTC is charged with providing realistic combat training to Army units, emphasizing coordinated air and ground tactics. An average of 3000 sorties per year (half of all tactical Army air operations in the US) are flown at NTC. Most air operations are conducted in helicopters below 50 feet AGL, and LLT prediction is a major concern.

Fort Irwin is a 2600 km^2 area in the Mojave Desert of California (Figure 1). It is characterized by a variety of terrains including high mountain peaks, broad valleys, and dry lake beds (Figures 2 and 3). Because of its location, NTC experiences a variety of weather and associated LLT: intense dry convective activity, thunderstorms, strong winds associated with frontal passages, and mountain waves. LLT

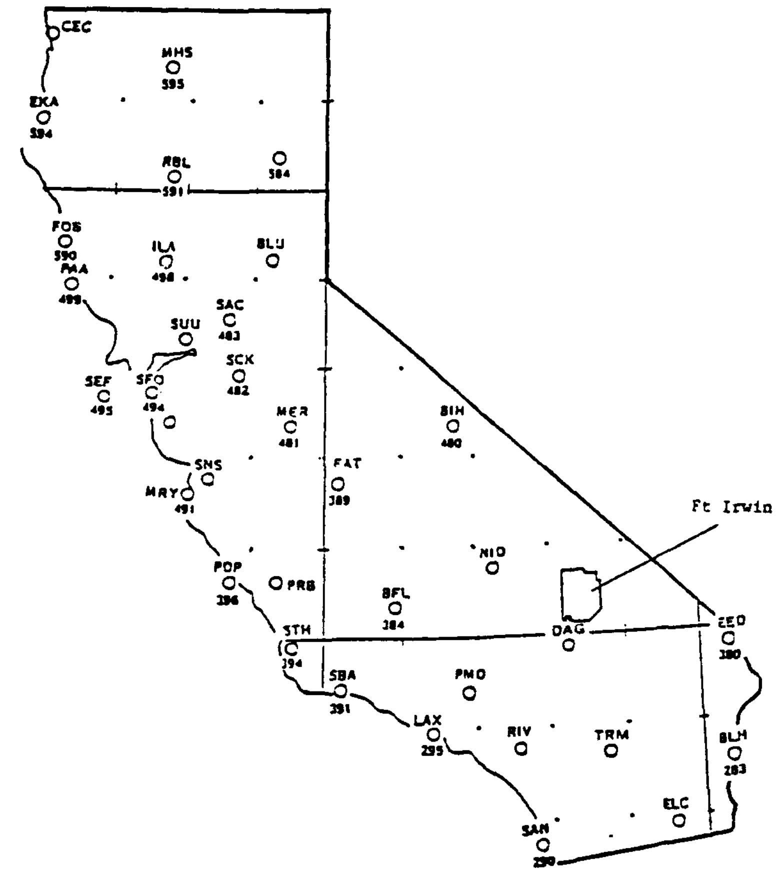

Figure 1 Ft Irwin Location

Circles represent surface reporting stations, indicating call sign and number.

Ft Irwin Terrain (200 m contours)

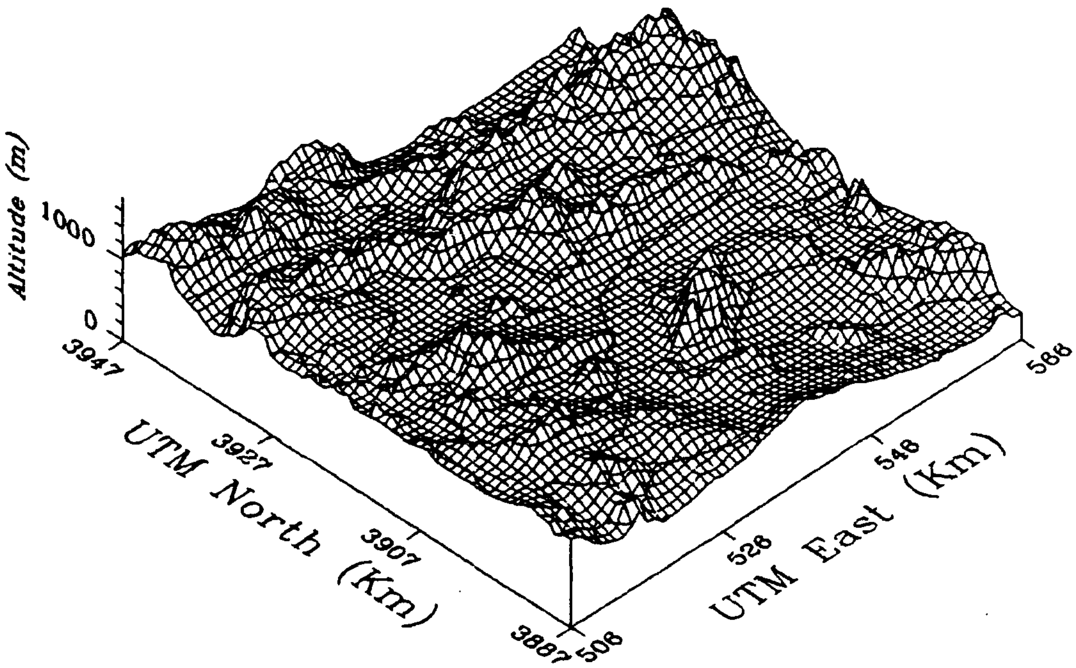

Figure 2 Three-Dimensional
View of Ft Irwin Terrain

Vertical scale exaggerated 10 times. View is from south-west.

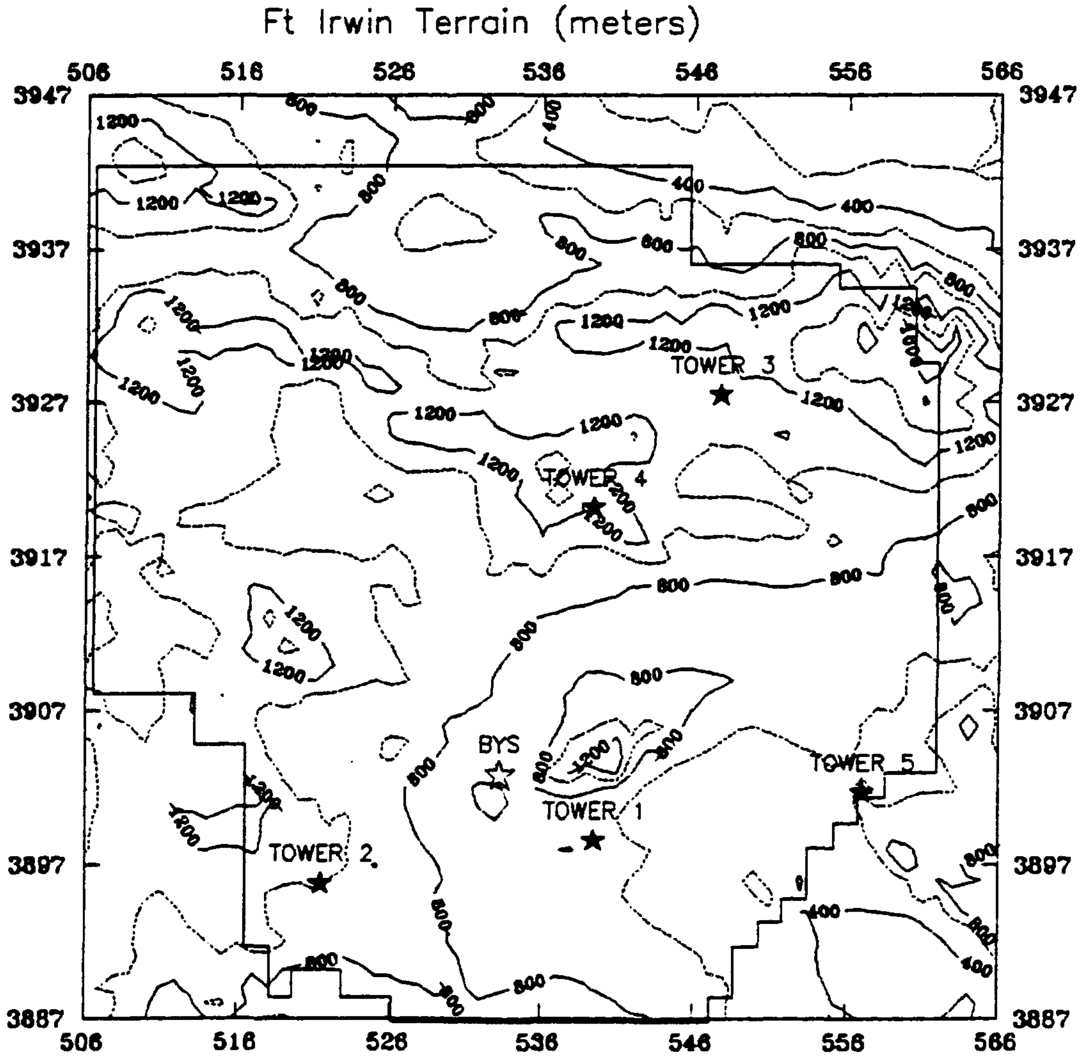

Figure 3 Ft Irwin Topography

Contours are at 200 meter intervals, axes are in Universal Transverse Mercator (UTM) kilometer coordinates. Meteorological sensors are located on Towers 1-5 as indicated. BYS is Bicycle Lake Army Air Field.

forecasts are complicated by lack of data and the rugged terrain prevalent at NTC. (Air Force, 1987)

Point warnings for NTC are issued by the US Air Force Global Weather Central (GWC), with supplemental forecasts issued by George AFB (VCV); operational forecasts are provided by forecasters attached to (transient) trainee units. The lack of forecaster experience compounds the LLT forecast problem at NTC. Transient forecasters have approximately three weeks to become familiar with the terrain and weather patterns common at NTC. Their natural tendency is to forecast conservatively in unfamiliar situations; this, coupled with an inability to resolve the scales involved and a lack of local observations, results in the user's perception that the forecasts are inaccurate (i.e. over-forecasts) (Lester and Burton, 1988). For example, an average of 20% of all missions during spring and fall are cancelled due to forecast LLT and/or predicted high surface winds (Marrs, 1988). Although some of these cancellations are clearly warranted, in many cases only a portion of NTC experiences LLT of critical intensities; i.e., flying activities could be conducted safely in other areas. Current LLT forecasts do not contain such detail and the post is either entirely open or closed to flying.

Recently, several experiments were carried out in an attempt to overcome the LLT forecast problem at NTC: (i) a network of automated surface weather stations was installed

(Marrs, 1988); (ii) a small computer scheme for real-time objective analysis and graphic display of terrain and winds across the post was developed (Henmi et al., 1987); and (iii) an automated (small computer based) system for general (point) forecasts of LLT at Ft Irwin was developed (Lee, 1988). In addition, Lester and Burton (1988): (iv) mapped turbulence prone areas at NTC (Appendix I); (v) initiated a turbulence data collection scheme; and (vi) expanded on earlier work by Burton (1964) and Ludwig and Endlich (1988) to demonstrate the feasibility of the real-time computation and display of a map of an objective index of LLT intensity for the local area.

These initial experiments have met with varying degrees of success. For example:

The increased number of observation stations, and the real-time display of the data on a map of the post was found exceptionally useful by the forecasters and pilots alike. However, better coverage of critical areas is needed. Although the interpolation of data from the improved network to all locations across the post via the Henmi (1987) mass consistent wind model provided the needed coverage, the influence of stability on the distribution of winds was ignored in the model.

The LLT forecast aid developed by Lee (1988) provides a useful training tool for forecasters unfamiliar with the area, as well as a semi-objective forecast "checklist" which

helps to standardize forecast methods and procedures. The main disadvantage of this method is that it yields only gross point forecasts which do not address the problem of turbulence gradients across the post.

The turbulence climatology developed by Lester and Burton (1988) is a useful familiarization tool for new forecasters. Also, their turbulence data collection program has resulted in a useful data set for winter and spring, 1988, at NTC. Their turbulence index scheme, however, has not been tested against extensive data.

The results of these preliminary experiments present a starting point for the significant improvement of LLT forecasts. The ability to manipulate large data bases and to execute relatively sophisticated physical models locally on small computers allows the forecaster to make more detailed analyses than are practical at a central facility. Furthermore, the incorporation of artificial-intelligence (AI) technology into forecast schemes offers the potential for a marked improvement in forecast accuracy and consistency (Racer and Gaffney, 1986).

1.2 Objective

The previous section has documented the need for research toward better LLT forecasts. Furthermore, the focus of recent LLT research at Ft Irwin has demonstrated improve-

ments which may be expected with the application of available small computer technology. The objective of the current research is to integrate and expand the NTC work to develop a small computer expert system for LLT forecasts.

1.3 Scope

The proposed expert system will be based on the objective low level Local-Scale Turbulence Index (LTI) proposed by Lester and Burton (1988). A brief review of current LLT forecast methods, the prototype LTI system, and AI methods will be presented in Chapter 2. System development is described in Chapter 3, with a description of available test data in Chapter 4. Program execution and results are presented in Chapter 5 followed by conclusions and recommendations (Chapter 6).

2. Background

2.1 Low Level Turbulence

"Turbulence" is commonly defined in terms of fluid behavior. For example, Huschke (1959) defines turbulence as "a state of fluid flow in which the instantaneous velocities exhibit irregular and apparently random fluctuations so that in practice only statistical properties can be recognized and subjected to analysis." In contrast, aviation turbulence is defined with respect to the aircraft which encounters it, e.g., as "bumpiness in flight." It follows that the intensity of aviation turbulence is usually expressed in terms of its effects on aircraft (Table 1). In fact, semi-quantitative Pilot Reports (PIREPs) of those effects are the most common form of aviation turbulence data available for both forecasts and research.

Low Level Turbulence (LLT) or "bumpiness in flight through the planetary boundary layer" is caused by a number of phenomena, including dry convection (thermals), moist convection (thunderstorms, downbursts, etc.), mechanical mixing, mountain waves, low-level wind shear, and fronts. These mechanisms are not mutually exclusive, but their separation is useful in the discussion of turbulent processes.

Table 1 Turbulence Categories (AWS, 1988)

Light turbulence may cause slight erratic changes in attitude and/or altitude. It produces a variation in airspeed from 5 to 15 knots. Seat belts may be required and occupants may feel a slight strain against restraints. Loose objects in the aircraft may be displaced slightly. Food service may be conducted and little or no difficulty is encountered while walking.

Moderate turbulence causes changes in altitude and/or attitude but aircraft remains in positive control. Airspeed is affected, varying from 15 to 25 knots. Occupants feel definite strain against restraints. Unsecured objects are dislodged. Food service and walking are difficult.

Severe turbulence causes large, abrupt changes in altitude and/or attitude. Airspeed is affected in excess of 25 knots. Aircraft may be momentarily out of control. Occupants are forced violently against seat belts and the seat. Loose objects are tossed about the aircraft. Food service and walking are impossible.

Extreme turbulence is very rare. The aircraft is violently tossed about and is practically impossible to control. Rapid fluctuation of airspeed occurs in excess of 25 knots. It may cause structural damage.

2.1.1 LLT Forecast Methods

Current LLT forecast procedures rely on the association of one or more large scale meteorological indicators with the occurrence of the mechanisms listed above. Examples are large scale flow patterns (FAA, 1987; AWS, 1988; Lee, 1988), calculated parameters or indices (Burnett, 1970; Lester and Burton, 1988), or rules of thumb often related to a threshold value of some meteorological variable (e.g. Lee et al., 1979).

Recognizing the subjectivity inherent in the application of these forecast procedures, Lester and Burton (1988) have presented a simplified flow diagram (Figure 4) to clarify the mental processes meteorologists use to formulate LLT forecasts. This procedure, although idealized, is comprehensive and will serve as a framework for further discussion.

As shown in Figure 4, "Pattern Recognition" refers to the identification of synoptic scale (and, where possible, mesoscale) flow patterns associated with LLT. The synoptic scale circulation patterns associated with LLT-generating phenomena have been well described. Synoptic patterns favorable for dry convection have been examined in the context of forecasts for soaring (Wallington, 1966; Lindsay and Lacy, 1976; Bradbury and Kuettner, 1976). Conditions conducive to the development of moist convection have long been

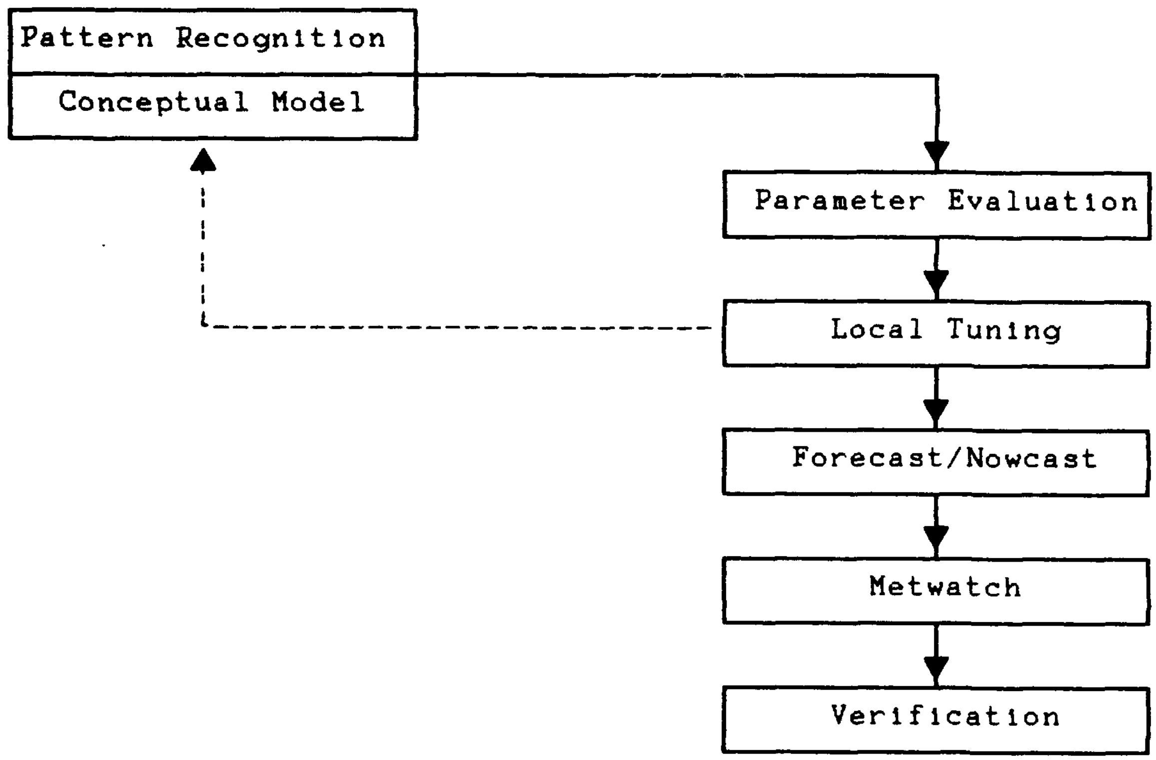

Figure 4 Idealized LLT Forecast Procedure

After Lester and Burton (1988)

of interest to operational forecasters, especially with respect to severe weather, and have been described repeatedly in the literature (e.g., Miller, 1972; Ray, 1986; AWS 1988).

Waters (1970), among others, has reviewed synoptic patterns frequently associated with strong, gusty winds of non-convective origin. Mountain wave patterns have been studied extensively with reviews by Alaka (1960), Nicholls (1973), and others. Frontal patterns are also described in numerous sources such as Pettersen (1956), Palmen and Newton (1969), Byers (1974), Chandler (1986), and AWS (1988). Additionally, local Terminal Forecast Reference Notebooks (TFRN) typically include local patterns favorable to the development of one or more of the conditions listed above.

With the exception of radar and satellite observation of moist convection, mesoscale circulation patterns are not as well measured as synoptic patterns. Lester and Burton (1988) note that, to fill this gap, an individual forecaster will develop a "Conceptual Model" based on accepted theory, on experimentally developed structural models, or simply on experience (Figure 4).

Mesoscale models of dry convection are described in the gliding literature cited earlier. Moist convective models have been well described by Palmen and Newton (1969), Byers (1974), Atkinson (1981), Fujita (1985), Ray (1986) and others.

Structural models of mountain wave systems have been applied extensively to infer areas of turbulence (Alaka, 1960; Nicholls, 1973; Lester and Fingerhut, 1974), and severe downslope windstorms (Lilly, 1978; Durran, 1986; Giusti, 1987) for many years.

Useful guidance for anticipating the location and intensity of mechanically generated turbulence and turbulence in the vicinity of fronts has received less attention (Theon, 1986; Chandler, 1986; AWS, 1988).

Once the likelihood of LLT is recognized, some sort of "Parameter Evaluation" (Figure 4) is used to determine the exact areas, times, and intensities of the expected turbulence. Lester and Burton (1988) group these parameters into three categories: (i) the basic meteorological variables, (ii) their spatial and temporal derivatives, and (iii) physical and/or empirical indices.

The forecast parameters associated with moist convection are extensive and well known (see, e.g., Ray, 1986; AWS, 1988). They include numerous stability indices and combinations of basic variables such as temperature, relative humidity, and wind shear. In addition, observational tools such as radar and satellites are useful in determining the location and intensities of thunderstorm elements.

Table 2 lists some common forecast tools for LLT not associated with thunderstorms. The simpler parameters

Table 2 Some Common LLT Forecast Tools
(After Lester and Burton, 1988)

<u>Dry Convection (Thermal) LLT</u>	
Surface Temperature	T_0
Temperature Lapse Rate	$\partial T/\partial z$
Potential Temperature Lapse Rate	$\partial\theta/\partial z$
Thermal Index (Higgins, 1963)	$T_z - (T_0 + \Gamma z)$ T_z = Temperature at 850 mb Γ = Dry adiabatic lapse rate
<u>Mechanical LLT</u>	
Surface Wind Speed and Gusts	$\overline{V}$, V'
Gradient Level Wind Speed	V_g
Terrain Roughness	Z_T
<u>Mountain Wave LLT</u>	
Mountain Top Wind Speed	V_x
Cross Mountain Sea Level Pressure Gradient	δP
<u>LLT Indices</u>	
Panofsky Index (US Navy, 1975)	$PI = V(1 - Ri/Ri_{CR})$ V = mean wind speed Ri = gradient Richardson # for boundary layer $Ri_{CR} = 10$
AFGWC Mechanical Turbulence Index (Burnett, 1970)	$I = aUR + b$ a, b = constants U = mountain top wind speed R = upwind terrain roughness

(e.g., surface temperatures) are often used because the vertical structure of the atmosphere in the area of interest is rarely known in great detail. The combination of parameters is frequently accomplished via indices (such as those shown at the bottom of Table 2), via "look-up" tables (e.g., Table 3), or with nomograms. Parameters for estimation of LLT in the vicinity of large-scale fronts usually depend on some knowledge of the intensity and speed of the front (e.g., Figure 5). Richwien (1979) has shown an association between significant LLT and frontal systems with horizontal temperature differences of at least 10 degrees F and frontal speeds of at least 30 knots. Fronts moving across rough terrain further enhance LLT production (Lester and Burton, 1988).

Threshold values for critical parameters are not universal; they are usually poorly defined functions of location, season, time of day, and aircraft type. Lee et al. (1979), the FAA (1987) and the AWS (1988) give typical values for these. The FAA (1987) also gives a useful summary of general rules of thumb derived from these parameters (Table 4). In addition, Lester and Burton (1988) note two other well-known, but frequently unstated, rules of thumb: (i) the intensity of turbulence always increases in proportion to wind speed and roughness; and, (ii) turbulence elements (hence surface gusts and LLT) have dimensions proportional to the size of the roughness elements.

Table 3 Low Level Turbulence Table
AWS (1988)

		Surface Wind Speed			
	Stability	1-12 kts	13-24 kts	25-50 kts	> 50 kts
Smooth Terrain	Very stable	O	L	L	M
	Relatively stable	O	L	M	M
	Relatively unstable	L	M	S	S
	Very unstable	M	M	S	S
Rough Terrain	Very stable	O	L	M	S
	Relatively stable	O	M	S	S
	Relatively unstable	L	M	S	S
	Very unstable	M	S	S	S

Letters indicate turbulence intensity as follows:

O: None L: Light M: Moderate S: Severe

Rough terrain is defined as a region where topographic features extend more than 1,000 feet above the surroundings.

The wind velocity used is the surface wind including gusts.

The stability categories apply to the layer from the surface to 850 mb and are defined as follows:

Very stable: A lapse rate equal to or less than the moist adiabatic rate.

Relatively stable: A lapse rate between the moist adiabatic and the mean lapse rate. The mean lapse rate is defined as that midway between the moist and dry adiabatic rates.

Relatively unstable: A lapse rate between the mean and dry adiabatic rates.

Very unstable: Lapse rate equal to or greater than the dry adiabatic rate.

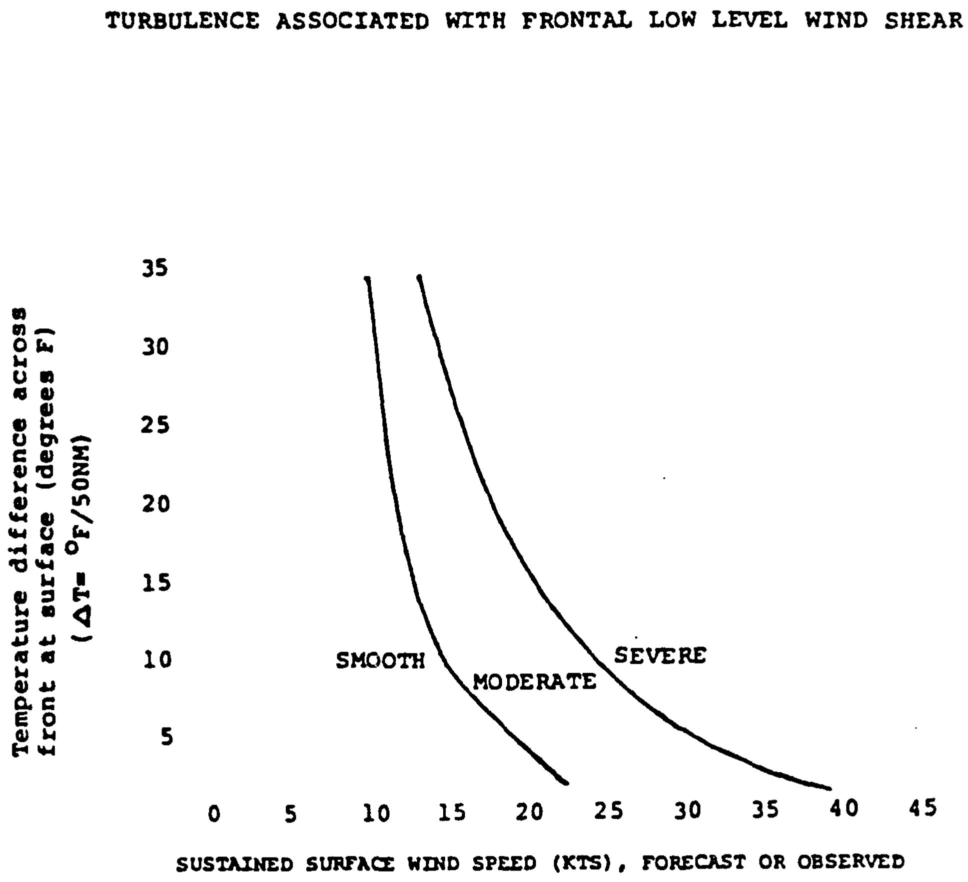

Figure 5 Turbulence Associated With Frontal Low Level Wind Shear

AWS (1987)

Table 4 Locations of Probable Turbulence by Intensities Versus Weather and Terrain Features (FAA, 1987)

Light Turbulence
1. In hilly and mountainous areas even with light winds.
2. In and near small cumulus clouds.
3. In clear-air convective currents over heated surfaces.
4. In the lower 5,000 ft of the atmosphere:
   a. When winds are near 15 kts.
   b. Where the air is colder than the underlying surfaces.

Moderate Turbulence
1. In mountainous areas with a wind component of 25 to 50 kts perpendicular to and near the level of the ridge:
   a. At all levels from the surface to 5000 ft above the tropopause with preference for altitudes:
      (1) Within 5000 ft of the ridge level.
      (2) At the base of relatively stable layers below the base of the tropopause.
      (3) Within the tropopause layer.
   b. Extending outward on the lee of the ridge for 150 to 300 miles.
2. In and near thunderstorms in the dissipating stage.
3. In and near other towering cumuliform clouds.
4. In the lower 5,000 ft of the troposphere:
   a. When surface winds exceed 25 kts.
   b. Where heating of the underlying surface is unusually strong.
   c. Where there is and invasion of very cold air.
5. In fronts aloft.
6. Where:
   a. Vertical wind shears exceed 6 kts/1000 ft, and/or
   b. Horizontal wind shears exceed 18 kts/150 miles.

Severe Turbulence
1. In mountainous areas with a wind component exceeding 50 kts perpendicular to and near the level of the ridge:
   a. In 5,000-ft layers:
      (1) At and below the ridge level in rotor clouds or rotor action.
   b. Extending outward on the lee edge of the ridge for 50 to 150 miles.

Extreme Turbulence
1. In mountain wave situations, in and below the level of well-developed rotor clouds. Sometimes it extends to the ground.
2. In severe thunderstorms (most frequently in organized squall lines) indicated by:
   a. Large hailstones (3/4 inch or more in diameter).
   b. Strong radar echoes, or
   c. Almost continuous lightning.

Refinement of these rules of thumb for specific areas occurs during the "Local Tuning" process (Figure 4), which is based on verifications from occasional pilot reports (PIREPS), knowledge of local conditions, and experience. Most rule modifications result simply in an increase or decrease of a critical threshold value.

The "Metwatch" function illustrated in Figure 4 entails monitoring conditions after a forecast has been made. Along with "Local Tuning," "Metwatch" is one of the most labor-intensive parts of the overall forecast process (Richwien, 1979); and, as pointed out by Lester and Burton (1988), the manpower required for this function is often unavailable, especially in critical forecast situations.

The last step in the forecast process is comprehensive "Verification" (Figure 4). This, of course, is required to monitor skill and improve the quality of the forecast product (McGinley, 1986). Due to the nature of low level turbulence data, this important step in the forecast procedure is often neglected.

2.1.2 LLT Forecast Problems

The primary problems associated with LLT forecasting are (i) scale, (ii) forecast subjectivity, and (iii) verification.

The critical time and space scales of turbulence are several orders of magnitude smaller than available measurements. For example, Roeder and Gall (1987) have estimated the width of a typical cold front as less than 20 kilometers. Jones et al. (1970), Murrow (1986), and others have shown the critical horizontal scale length of atmospheric turbulence to be on the order of one kilometer or less, and time scales on the order of minutes. Terrain scales important to turbulence generation may also be as small as ten meters (Theon, 1986). As a result of observational inadequacies, important turbulence variables such as atmospheric lapse rate (stability), wind speeds, pressure and temperature gradients must be interpolated or estimated in some way before their inclusion in any LLT forecast scheme. Clearly, this process decreases the accuracy of the forecast product.

Subjectivity affects forecasters and pilots alike. The "Pattern Recognition" and Local Tuning" tasks listed earlier are highly subjective, and can vary significantly with forecaster experience, training, and familiarity with the local area. AWS (1988) cites the natural trend to over-forecast certain categories and under-forecast others. The turbulence categories themselves (e.g. "Moderate," "Extreme," Table 1) introduce further subjectivity into the forecast. Brown and Murphy (1982) have shown the superiority of a numerical index to verbal categories which

are likely to mean different things to different people. Participants at a recent turbulence workshop conducted by the National Aeronautics and Space Administration (NASA) agreed, listing the standardization and quantification of turbulence intensity terms as "high priority" (NASA, 1986).

"Verification" is another problem area in the development of an acceptable LLT forecast technique. Accurate turbulence data bases are difficult to collect, given the expense of instrumented observations and the subjectivity of PIREPs. To date, the verification of LLT forecasts has depended almost solely on the latter. Keller (1986) has emphasized the subjective nature of PIREPs, pointing out that pilots aren't "blind" sensors, they react to encountered turbulence, and avoid areas where it is forecast. Furthermore, during a turbulence encounter, pilot corrective action can actually increase aircraft buffeting due to the phase relationship between the turbulence and corrective action. These problems are exacerbated by differences in pilot experience, and aircraft type and speed. Despite this subjectivity, PIREPs remain the most effective means of collecting large amounts of data over a given area.

2.2 Artificial Intelligence (AI) and Expert Systems (ES)

Recent advances in small computer technology provide new opportunities for improved local forecasts. Desk top computers now have the capacity to handle large data bases and to execute relatively sophisticated physical models in near real time. AI technology promises to increase forecast consistency and reliability by bringing all forecasters up to the same level of experience. Smith (1988) has recently reviewed AI applications to forecast problems, and the following is based partially on that review.

Artificial Intelligence (AI) is a generic term referring to the use of a computer to imitate human behavior which is generally thought to require intelligence. Expert Systems (ES) and Knowledge Based Systems (KBS) are less stringent terms dealing with the use of computers to emulate human thought processes under stricter guidelines using empirical relationships based on experience and knowledge of the programmer. Racer and Gaffney (1984) introduce the term Interpretive Processing (IP) as an application of ES/KBS in meteorological applications and quote the following definitions:

Artificial Intelligence is a subfield of computer science concerned with the concepts and methods of symbolic inference by a computer and the symbolic representation of

the knowledge to be used in making inferences. A computer can be made to behave in ways that humans recognize as "intelligent" behavior in each other. (Feigenbaum and McCorduck, 1983)

According to Duda and Shortliffe (1983), Artificial Intelligence is the development of computer programs that can solve problems normally thought to require human intelligence.

Nau (1983) defines Expert Systems as problem-solving computer programs that can reach a level of performance comparable to that of a human expert in some specialized problem domain.

By contrast, Duda and Shortliffe (1983) define a Knowledge-Based system as an AI program whose performance depends more on the explicit presence of a large body of knowledge than on the possession of ingenious computational procedures; by expert system they mean a knowledge-based system whose performance is intended to rival that of human experts.

Interpretive Processing (IP), as used here, is a computer interactive procedure that enhances the abilities of the weather forecaster to decide on a forecast. The procedure makes it easier to draw conclusions from the meteorological analysis of observational data, forecasting techniques, and past forecaster experience available when deciding on a forecast.

The possible applications of AI to meteorology cover a spectrum, ranging from decision trees, such as developed by Brown (1986) and Colquhoun (1987) to forecast programs capable of learning (Gaffney and Racer, 1983) and beyond. The National Weather Service is increasing its automation of field operations as part of its modernization efforts, with one of its areas of concentration being the field of Interpretive Processing. Since the forecast problem involves reduction of available data, identification of significant data and guidance (numerical and manual), and the application of both explicit and implicit relationships, rules of thumb, etc. to create a forecast product, a competent IP system would be of great benefit. Racer and Gaffney (1984) give an example of a prototype IP system tailored to NWS needs. They further envision a three-fold benefit from the application of ES/KBS to weather forecasting: (i) to provide improved data analysis and decision-making support due to enhanced consistency and thoroughness; (ii) to support training of new forecasters; and, (iii) to support skill maintenance for experienced forecasters, especially with regard to their actions in infrequently-occurring, unfamiliar situations. Successful incorporation of these objectives into a comprehensive LLT forecast scheme would improve forecasts significantly.

AI technology is being used in varying degrees as a forecast tool. Brown (1986) has developed a simple decision

tree approach to forecasting downslope wind storms in Colorado. His is a program using "if-then" structures to consolidate significant data (both analysis and numerical guidance) into a valid indicator of the probability of strong downslope winds. Colquhoun (1987) has used a similar approach in the forecasts of thunderstorms and tornadoes. Gaffney and Racer (1983) have developed a prototype system for severe storm advisories which is capable of "learning" behavior. This system is based upon formalized rules developed by Crisp (1959) and Miller (1972) of the Air Force Global Weather Central. Racer and Gaffney (1986) quote a personal communication with J.T. Schaefer of the National Severe Storm Forecast Center detailing a KBS which includes "a severe weather checklist of 10 parameters which are evaluated as a group using 'if-then' rules to determine the 'possibility' of a storm." Racer and Gaffney (1986) also detail a diagnosis procedure for evaluating numerical guidance materials developed by Simpson (1971) at the NWS National Hurricane Center. It uses a decision ladder for systematic analysis of the performance of numerical models with the goal of improving them.

There is an apparent gap in the spectrum of technical applications of AI to weather forecasting. Gaffney and Racer's "learning" program is at the high end, but it is only a prototype. The checklist/decision tree approach (e.g., Lee, 1988), at the low end of the spectrum, is the

only application of AI currently in use. While this is an improvement over manual methods, much greater benefits could be realized by the use of "smarter" systems.

2.3 The Local Scale Turbulence Index (LTI) -- A Prototype Expert System for LLT Forecasts

The Burton Turbulence Index is a non-dimensional numerical index used to describe expected turbulence intensities over a large area. BTI uses three of the forecast tools shown in Table 2 to characterize LLT: (i) gradient wind speed and (ii) surface roughness as indicators of mechanical LLT, and (iii) temperature lapse rate to indicate dry convective or thermal LLT. Moist convective (e.g., frontal) LLT is addressed by a fourth parameter, the surface pressure tendency. BTI has been used operationally as a macroscale LLT forecast tool in the past; Lester and Burton have recently shown that, with modifications, BTI may be adapted to finer scales.

BTI is defined as

$$BTI = R + V + S + T \tag{1}$$

where R is roughness (difference between the highest and lowest elevations) in hundreds of feet, V is the wind speed in knots at 2000' AGL, S is ten times the lapse rate in

°C/1000 ft in the lowest 100 mb, and T is the absolute value of the 3-hour pressure tendency.

The BTI was used extensively from the mid nineteen-sixties through the early seventies as a large scale LLT indicator at the US Air Force Global Weather Central (GWC) (Burton, 1964; Burnett, 1970). Table 5 lists critical BTI values for category I aircraft (i.e., those aircraft most susceptible to turbulence).

Jones (1970) has investigated the use of wind speed, lapse rate, roughness, BTI, Richardson number, and Showalter index in the prediction of LLT using data collected from the US Air Force LO-LOCAT project (Loving, 1969). The results clearly demonstrated the usefulness of BTI in comparison to the other variables and indices.

Lester and Burton (1988) developed a prototype local-scale turbulence index (LTI) on a mesoscale (ß,τ) grid for NTC. The LTI is a scaled version of the BTI, and is calculated as follows:

$$LTI = BTI \times (R_j + V_j)/(R + V)_{max} \qquad (2)$$

R_j = the roughness (as defined for BTI) for a two kilometer square centered on grid point (j).

V_j = the 10 m wind speed at grid point (j), determined from local observations and a diagnostic wind model.

Table 5 BTI Turbulence Categories (Lester and Burton, 1988)

Category	BTI
Light	60
Moderate	70
Moderate/Severe	90
Severe	100
Extreme	120

$(R + V)_{max}$ = the maximum value of $(R_j + V_j)$ across the model domain.

LTI has shown promise as an improved method for LLT forecasts in the Ft Irwin area, and is the basis of the system developed and applied in the following sections.

3. LLT Algorithm Development

3.1 General

Having identified the BTI/LTI as a basis for an expert system with the potential for meeting both scientific and operational needs for LLT prediction over a mesoscale area, an LLT forecast algorithm for Ft Irwin has been developed and is discussed in the following sections.

The forecast system is designed to satisfy the following practical requirements:

(i) User-friendly to compensate for differing levels of forecaster computer experience; the system must be easily accessible to operators of all experience levels.

(ii) Executable on a common microcomputer (e.g., IBM PC/AT or comparable system); the system actually used employed an 80286 microprocessor and 80287 co-processor, with a 40 megabyte hard disk drive, 1 megabyte of random access memory, and an Extended Graphics Adaptor (EGA) color monitor.

(iii) Executable in nearly real time; the system must provide accurate decision assistance in a timely manner to ensure its inclusion in the forecast.

(iv) Minimal keyboard inputs, because forecaster time is often at a premium.

(v) Suitable for adaptation to other areas and data bases.

(vi) Modular structure to permit improvements to the system to be made more easily.

In order to meet the meteorological requirements listed above, three program modules are required to process information in such a fashion as to be the most useful for the forecaster. The primary forecast decision aid, and the part which required the major development effort, is the forecast module. Secondary components are the archive module, which stores PIREPs for use both in real time in the forecast module and in future research, and the tutorial module, which instructs the forecaster on the use of the program. Figure 6 illustrates the program structure and the relationships of the modules to each other. Appendix II presents FORTRAN code for all elements in the program.

The BTI was originally developed as an empirical, non-dimensional index derived from parameters commonly available from aviation observations and forecast products. Consequently, a mix of units (English and metric) were used. As it is the aim of this program to allow forecasters to input data directly from available resources, the mixed unit convention was maintained in the development of the LTI, and is used in the LTI program and discussion which follows. All necessary unit conversions are performed in the computer code, and are transparent to the user.

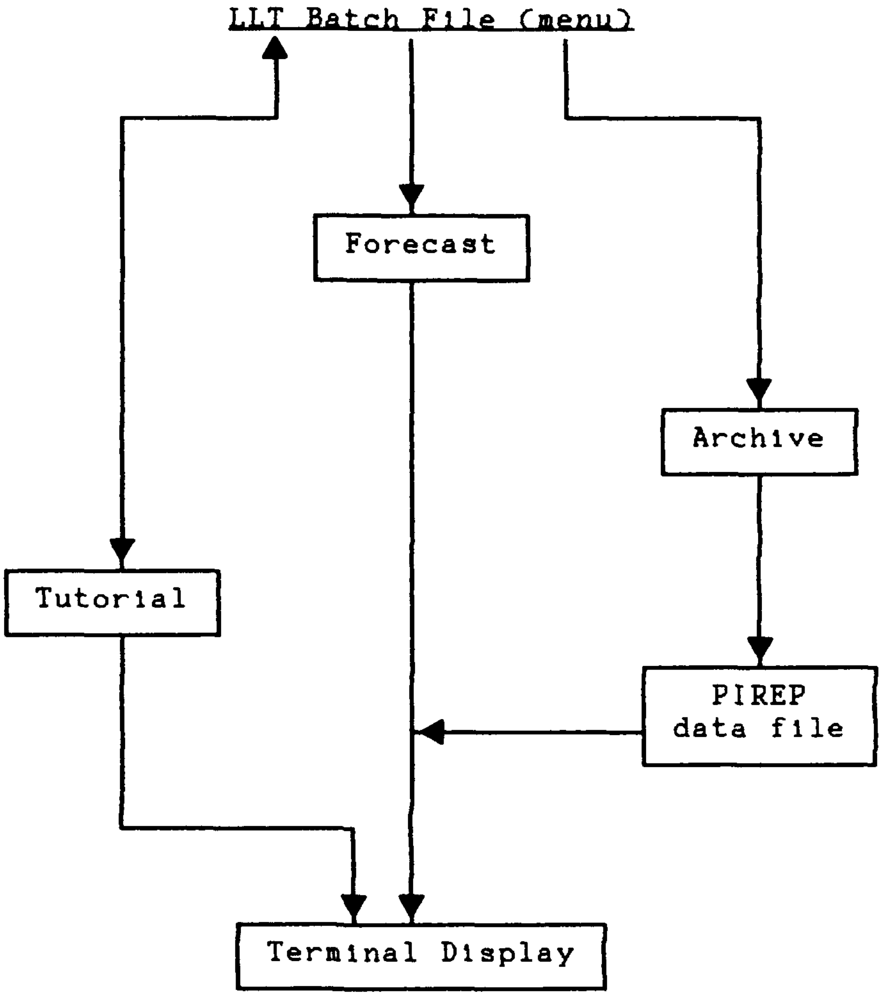

Figure 6 LTI Program Architecture

3.2 Forecast Module

The forecast module produces the actual decision aid. It is composed of six FORTRAN programs and one C program for on-screen graphics (Figure 7). A list of the programs and their functions is presented in Table 6. The module uses the basic procedure developed by Lester and Burton (1988) to produce an initial "raw" Local scale Turbulence Index (LTI) at 1 km intervals across the NTC complex. The "raw" LTI is modified to account for increased "wake" (lee side) turbulence, and recent PIREPs. Contours of turbulence category thresholds are displayed superimposed on 200 meter terrain contours.

3.2.1 Raw Local Turbulence Index

Roughness

A macroscale (BTI) roughness of 59 (R in equation 1) was calculated from the difference between the highest and lowest elevations in the domain of the model (i.e. Ft Irwin). The LTI roughness values at each grid point were then computed in the same manner for a 1.0 km square centered on the grid point. All roughness values were computed using 100 meter terrain data provided by the US Army Atmospheric Sciences Laboratory (ASL). Contours of

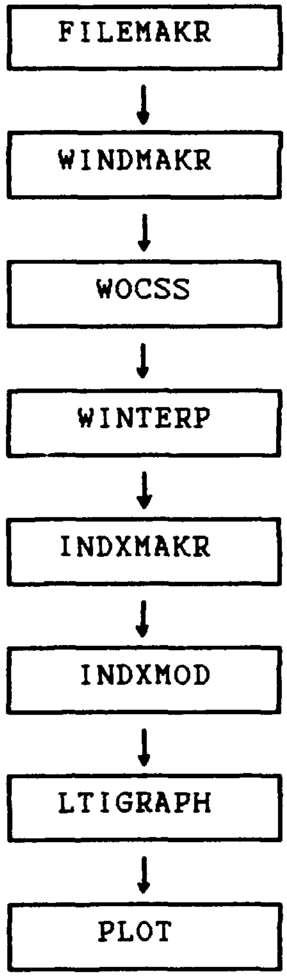

Figure 7 Forecast Module Architecture

Table 6 Forecast Module Architecture

Program	Function	Files Read	Files Created
FILEMAKR	Keyboard Input/ user interface		MAINDATA.DAT
WINDMAKR	Creates WOCSS input files	MAINDATA.DAT	WINDS.DAT TEMPS.DAT
WOCSS	Wind model	WINDS.DAT TEMPS.DAT [1]TERRAIN.DAT	SPD.DAT DIR.DAT
WINTERP	Interpolates horizontal winds to 61X61 grid; calculates w	SPD.DAT DIR.DAT [1]X.DAT [1]Y.DAT	WINDVEL.DAT WINDDIR.DAT W.DAT
INDXMAKR	Calculates raw LTI	MAINDATA.DAT WINDVEL.DAT WINDDIR.DAT [1]RUFFILE.DAT	RAWINDEX.DAT [2](WR.DAT)
INDXMOD	Modifies LTI for wake and PIREPs.	RAWINDEX.DAT W.DAT MAINDATA.DAT [3]PIREP.DAT [1]TERRTYPE.DAT	NEWINDEX.DAT PRP.PLT
LTIGRAPH	Creates plotter commands for display	[1]NTC1000.PLT NEWINDEX.DAT PRP.PLT	PLOT.DAT
PLOT	Graphics output	PLOT.DAT	

[1] Resident data files.
[2] Scratch file.
[3] Created in ARCHIVE module.

the roughness values (based on 1-kilometer squares) for Ft Irwin is presented in Figure 8.

Winds

Wind inputs for the BTI (V in Equation 1) were initially inferred from the 850 mb surface as described below. As will be shown in a later section, the resulting BTI values were unrealistically high. To reduce the magnitude of V, and hence BTI, wind speed at 5 m was taken from a representative location (Tower 2, Figure 3). See Section 4.1 for a description of the meteorological sensors used.

LTI (grid) wind inputs were calculated using the Ludwig and Endlich (1988) Winds on Critical Streamline Surfaces (WOCSS) model. The WOCSS model uses available measures of vertical wind and temperature profiles to define surfaces within which air flow takes place. Critical streamline concepts are used to define these surfaces, which can intersect the terrain under stable conditions; this forces flow around topographical obstacles. In this application, WOCSS provided a convenient method by which limited observations could be objectively assimilated to provide a gridded estimate of near-surface winds. Inputs to WOCSS include terrain, vertical temperature and wind profiles, and surface winds. The WOCSS model was chosen on the basis of its more realistic treatment of the vertical structure of

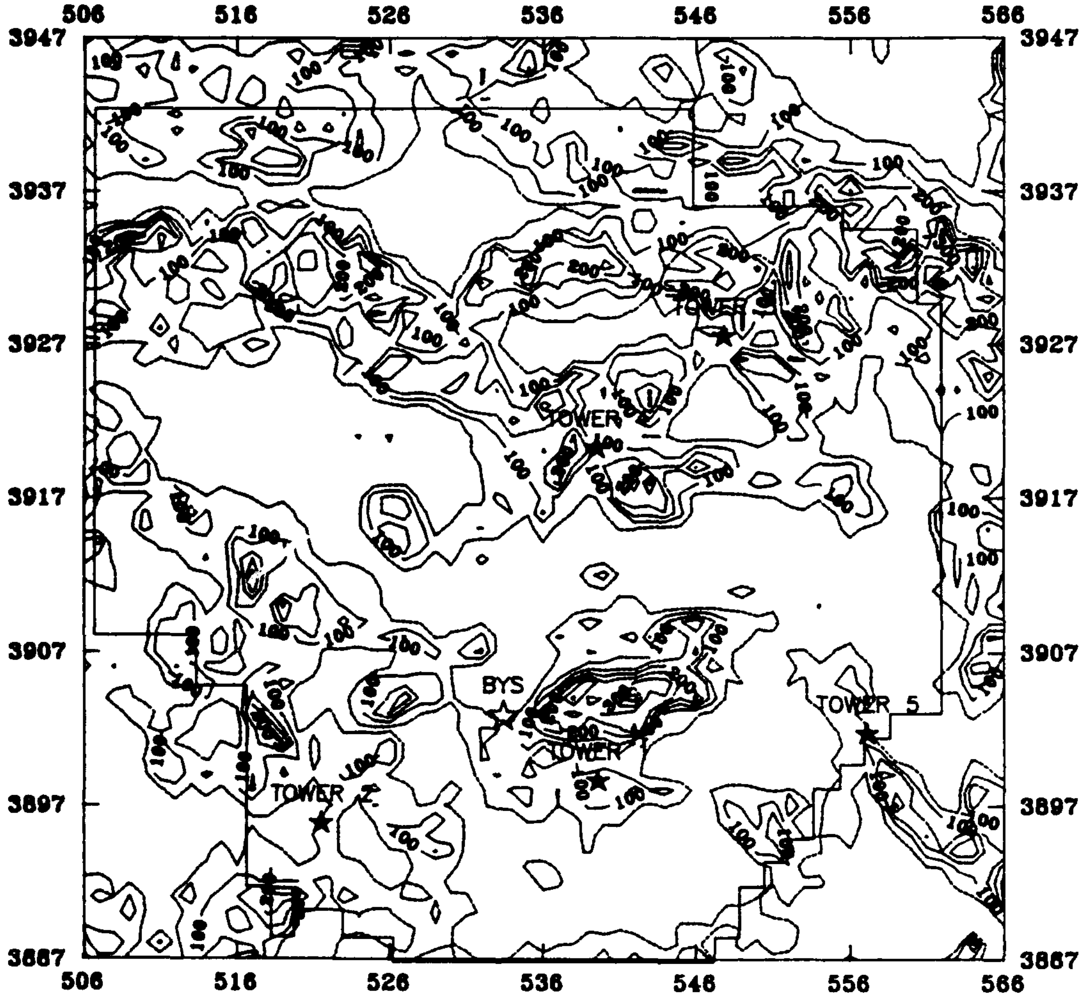

Figure 8 Contours of Ft Irwin Terrain 1-Kilometer Roughness Values

Roughness contours labeled in tens of feet. Axes are UTM (km) coordinates. See text for roughness calculation.

the atmosphere in the wind interpolation, and because it was available with complete documentation. The choice of wind interpolation scheme is not critical to the mechanics of the LLT forecast, although inaccuracies here will lead to poor forecasts.

While the WOCSS model is capable of handling a 61 x 61 (i.e., 1.0 km) grid point domain, the resulting executable file is 1.9 megabytes, too large for most microcomputers. Two attempts were made to resolve this problem. Initially the nested grid capabilities of WOCSS were examined, using a course grid at 2.0 km spacing and four finer grids, each at 1.0 km and comprising one quarter of the model domain. The four resulting 1.0 km wind fields were then merged into one. This approach proved inadequate due to inconsistencies at the boundaries of the quarter grids and excessive time required to do the 4 model runs (approximately 20 minutes).

The second approach simply calculated winds on a 31 x 31 (i.e., 2.0 km) grid and then used a linear interpolation to obtain the 1.0 km values. In this process, the initial winds are resolved into u and v components, interpolated, and combined into direction and speed values. This reduced the time to complete a single model run to 5 minutes.

Towers 1 - 5 (Figure 3) were assigned as surface observation Sites 1 - 5 (see section 4.1) in the WOCSS input file (Table 6). As the model assigns the tower locations to the nearest grid point, it became necessary to alter the

input tower elevations to match the grid. This prevented the model from disregarding tower inputs as beneath the terrain.

For operational ease and due to sparse data, observations at only two levels were used to specify the vertical structure inputs to the WOCSS model: surface (i.e., Tower 2) and the estimated top of the mixing layer. Experience has shown the WOCSS model to be more realistic when the top of the domain is above any stable layers that will affect the flow (Ludwig, 1990). Since terrain heights vary between 60 and 1780 m above mean sea level (MSL), a compromise mixing layer height of 2000 m MSL was assumed, with temperature and pressure extrapolated from 850 mb synoptic charts as follows:

Temperature was extrapolated from the 850 mb level to 2000 m using the surface - 850 mb lapse rate. The lapse rate was calculated using temperatures and heights from Tower 2 and the synoptic 850 mb chart.

Pressure at 2000 m was estimated from the synoptic 850 mb height assuming a linear 10 mb decrease in pressure per 100 m increase in altitude. This assumption is a valid approximation near 850 mb with normal 850 mb temperatures and heights.

As 2000 m winds are not normally available, they must be inferred from another source. Geostrophic winds computed from surface observations are inaccurate due to the complex

terrain and high elevations. Therefore, winds from the nearest synoptic constant pressure surface (850 mb) were used as the best available approximation for 2000 m winds for input to the WOCSS model.

Stability and Pressure Tendency

The surface - 850 mb lapse rate calculated for the WOCSS model is also used for the stability input to the BTI (S in Equation 1). Pressure tendency (T in Equation 1) is taken directly from Tower 2 output.

3.2.2 Index Modifications

Once a "raw" LTI has been calculated at grid points via Equation 2, the program adjusts the index based on PIREPs and anticipated wake enhancements of turbulence. For aircrew safety, the modifications are deliberately conservative, i.e., the raw LTI may be increased, but is never reduced by the index modification scheme.

Wake Enhancement

This modification was conceived after discussions with Ft Irwin pilots indicated that there was a significant difference in turbulence up- and downstream of mountain peaks and crests, i.e., turbulence was more common on the lee slopes of the mountains. These remarks are in agreement with experimental and theoretical studies of airflow over mountains (e.g., Baines, 1987). It should also be noted

that neither the BTI/LTI scheme (Equations 1 and 2) nor the WOCSS model explicitly deals with the generation of wake turbulence.

The "lee" slopes of individual terrain features can be identified by the sign of the terrain-induced vertical velocities. These are derived from the dot product of the interpolated horizontal wind ($\mathbf{V}_H$) and the topography H(x,y) (Figure 9), i.e.,

$$w = \mathbf{V}_H \cdot (\partial H/\partial x\mathbf{i} + \partial H/\partial y\mathbf{j})$$

where

$\mathbf{V}_H$ = horizontal surface wind vector

H = terrain height = H(x,y)

The "lee" sides of the terrain features are those regions where $w < 0$ (Figure 9).

Assuming that wake turbulence is more likely where magnitudes of vertical velocities are large, experiments were conducted to determine the appropriate w threshold at which modify the LTI. Thresholds tested were $w < 0$, -0.5, -1 and -1.5 ms^{-1}. The LTI fields generated using 0 and -0.5 ms^{-1} thresholds were unrealistically large compared to pilot observations, i.e., they resulted in the selection of 30-40% of the post area for modification. A threshold of -1.5 ms^{-1} was more realistic and is in agreement with an observational study by Lester (1974) which showed that a vertical velocity of -1.5 ms^{-1} was the threshold for "weak" lee waves and their associated turbulence. This value was used in the

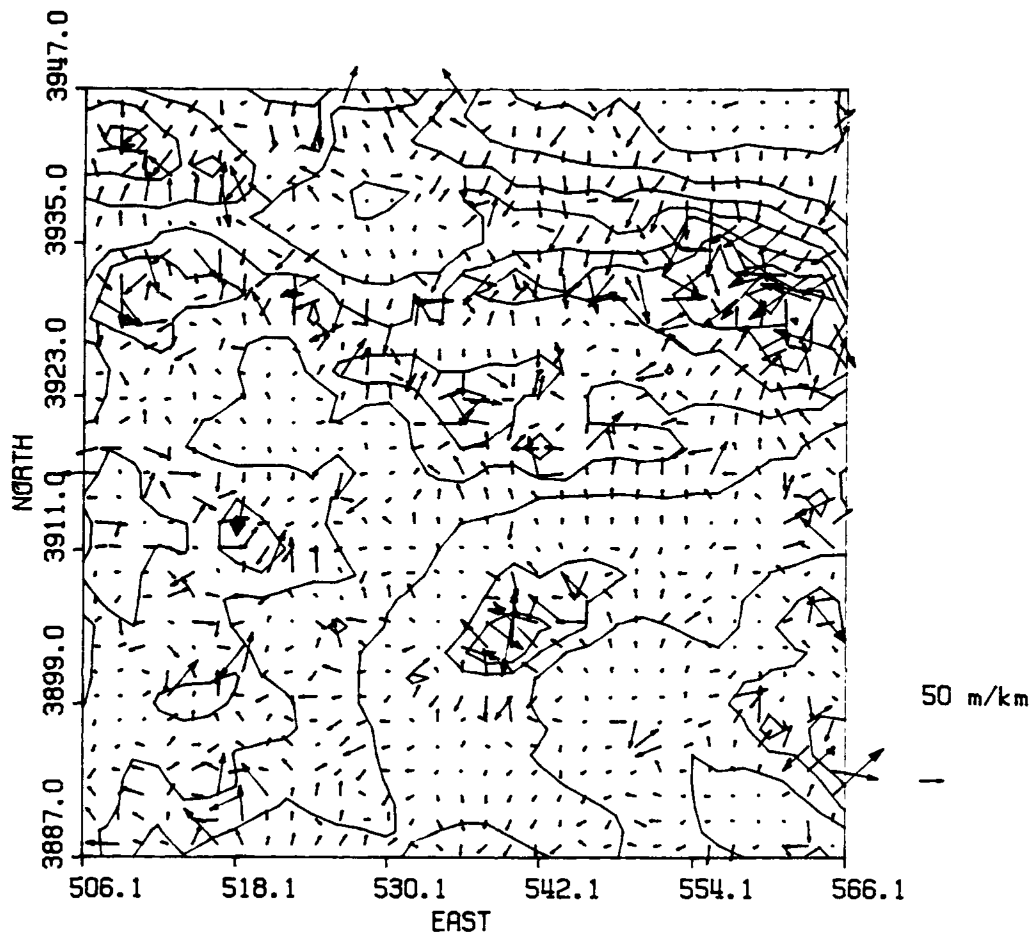

Figure 9 Ft Irwin Terrain Slopes

Vectors indicate magnitude and positive (up-slope) direction of terrain height gradient. Arrow at lower right shows scale for 50 m/km terrain height gradient.

current study. An example is shown in Figure 10.

Once the areas to be modified were identified, the degree of modification had to be specified. Consultation with Burton (1989) indicated that forecast turbulence should increase by one category in the areas identified above. The simplest way to accomplish this is to increase the LTI value by 20 in these areas. This has the desired effect of an increase of one turbulence category in most areas, with two exceptions: (i) areas indicating severe turbulence may or may not increase to extreme, a moot point as in either case aircraft would avoid the area, and (ii) a non-turbulent value (<60) could be upgraded two categories to moderate (>70). This latter case is unlikely, since the horizontal wind velocities required for terrain induced vertical velocity to exceed the threshold for LTI modification are normally large enough to ensure a raw LTI greater than 60. Figure 11 shows the program logic for the wake modification.

PIREP Modification

PIREPs are the sole connection between the forecaster and verification of his/her turbulence forecasts; consequently, any comprehensive LLT forecast plan must include them. The method for incorporating PIREPs into the LTI is described in this section.

Due to short turbulence time scales, current forecast procedures consider PIREPs useful if they are less than one hour old (AWS, 1988). On this basis, and after the raw LTI

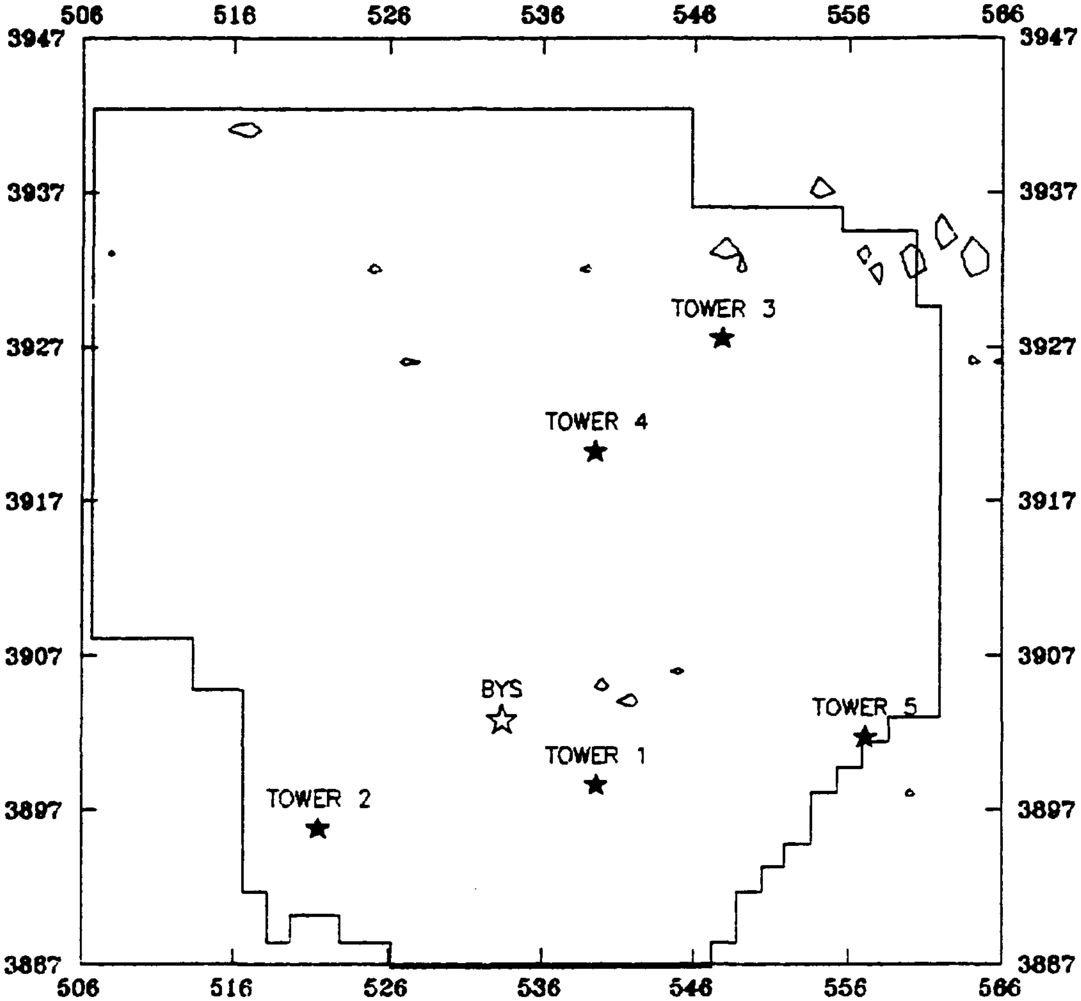

Figure 10 Example of Wake Modification Criteria

Polygonal shaped regions are areas of calculated negative (downward) vertical winds less than 1.5 ms^{-1}. Winds calculated using WOCSS model output for 0000 GMT 1 March 1988.

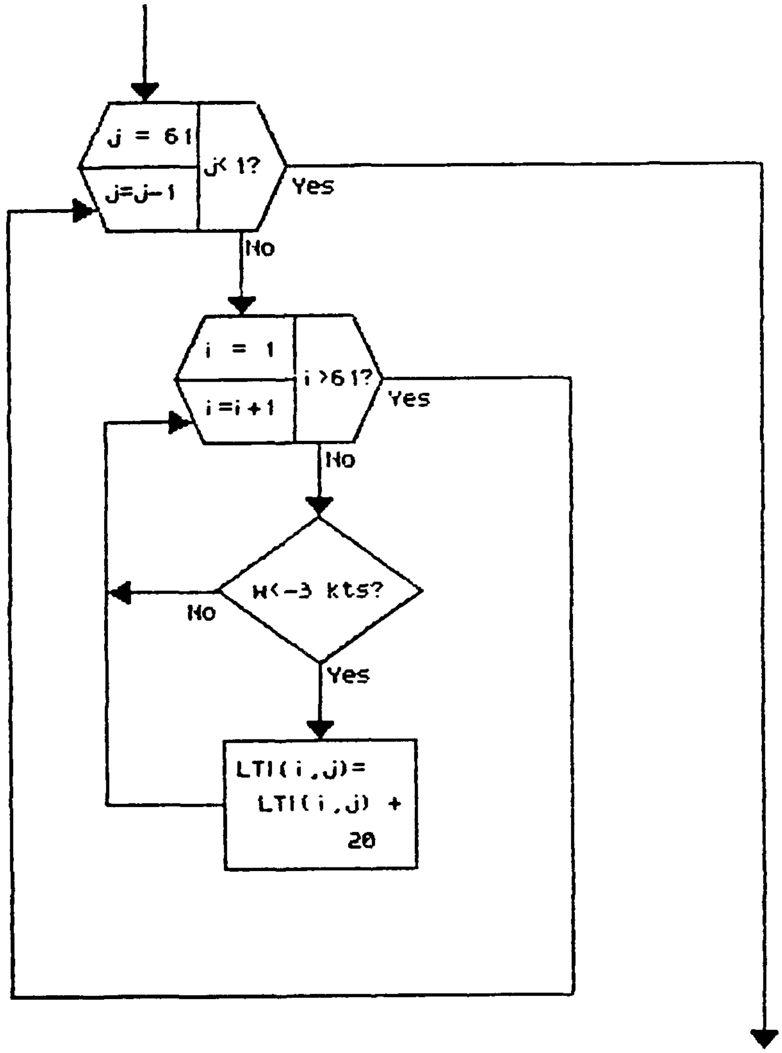

Figure 11 Wake Modification Program Logic

Raw LTI is increased by 20 at grid points with negative vertical velocities greater than 3 knots in magnitude.

has been modified for wake-enhanced turbulence, the program searches the PIREP data base (described in Section 3.3) for reports less than one hour old. For safety, current reports are assigned an index value at the upper end of their turbulence category. Therefore, reports of "light," "moderate," and "severe" turbulence would be assigned LTI values of 69, 89, and 119 respectively (Table 5). The PIREP LTI is then compared to the LTI at the nearest grid point. If the current value at the grid point is greater than or equal to the PIREP value, the PIREP is ignored and the program searches for more PIREPs. If, on the other hand, the LTI is less than the PIREP, the grid point is assigned the LTI value of the PIREP, and the ratio of the modified LTI to the initial LTI is calculated.

After modification of the LTI at the grid point nearest to the PIREP, the rest of the LTI field is considered for modification by assuming that similar terrain in other areas will induce similar turbulence intensities. Therefore the LTI field is modified for each PIREP in all areas of similar terrain.

Although terrain can be described by a number of parameters, such as altitude, roughness, slope, orientation, etc., in the present study, slope and orientation were chosen as the most important terrain characteristics for the production of turbulence (Chapter 2). More specifically, terrain is judged to be similar when comparing grid points

if the direction of the slope is within 30° and the magnitude is within 10 m per km. These data have been calculated and combined into a four-digit number for each grid point and stored in a terrain characteristics data file. The first two digits represent the positive (up-slope) direction on a 12-point compass (North ± 15° = 1). The final two digits represent the magnitude of the terrain slope in tens of meters per kilometer.

During program execution, the terrain characteristic at the PIREP location is determined first, then the LTI values at grid points with similar terrain (i.e., the same terrain characteristic value) are multiplied by the ratio calculated earlier (Figure 12). The program simply searches the terrain characteristic data file for grid points with values within the specified ranges, and alters the LTI at those points.

3.2.3 Display

In order for the final display of the LTI field to be useful, it must be unambiguous, easily read, and easily understood. To satisfy these requirements, a contour map of the LTI field is generated on the computer screen, with turbulence category thresholds (for Category I aircraft) displayed in color. 200 m terrain contours and a map of Fort Irwin are underlaid in the background for reference.

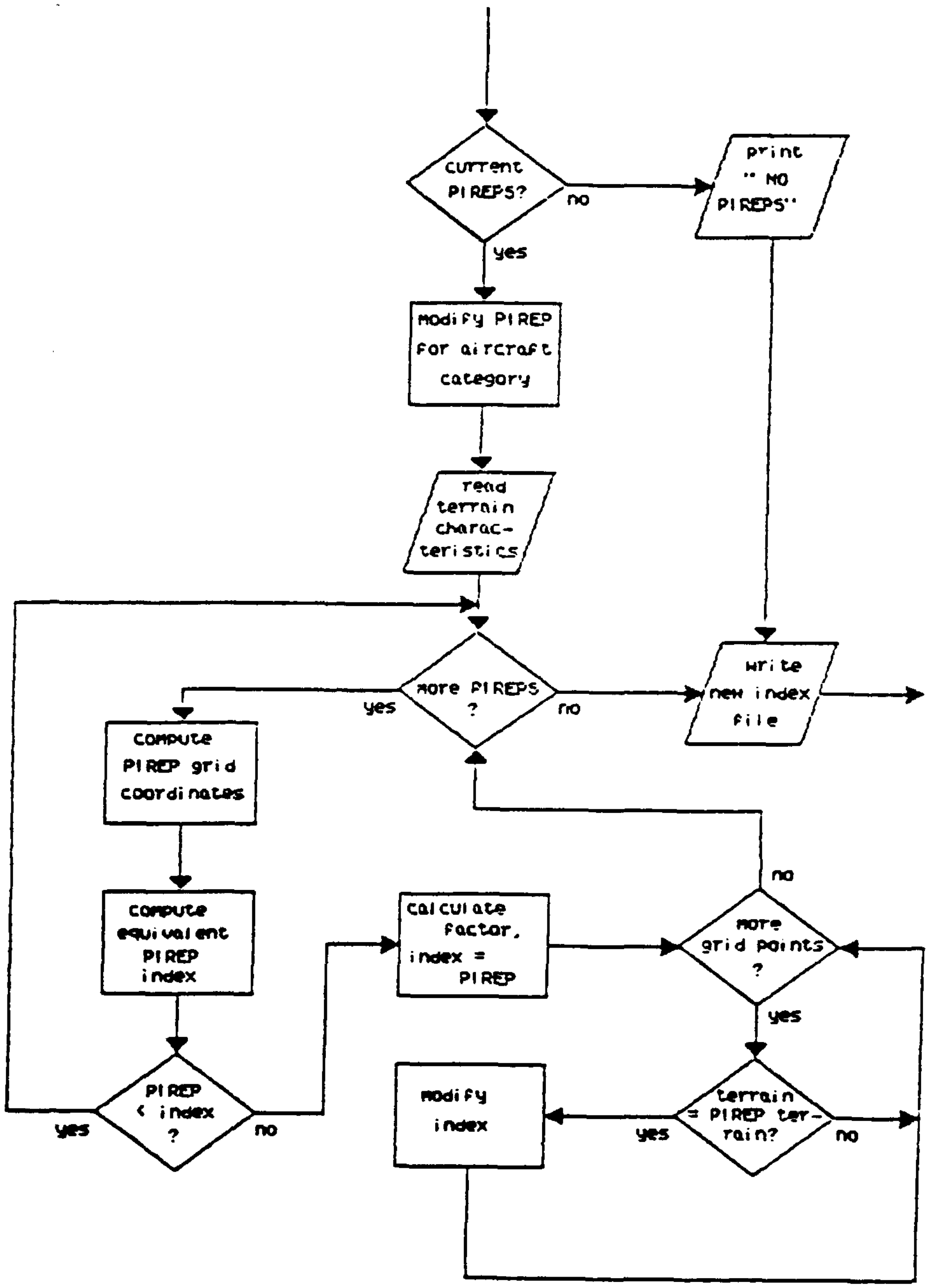

Figure 12 PIREP Modification Program Logic

See text for explanation.

The display programs were provided by ASL (Tabor, 1988), and modified for use with the LTI program. They consist of one FORTRAN program (LTIGRAPH), and one C program (PLOT). LTIGRAPH is a contouring program that creates and stores Hewlett-Packard plotter commands in a data file; PLOT translates these to screen commands for the EGA color monitor. While PLOT was used as supplied, LTIGRAPH was modified as follows: (i) the terrain contours were fixed at 200 m, (ii) only threshold LTI contours were displayed, (iii) a map of Ft Irwin boundaries was added, (iv) the resolution was increased to 1.0 km, and (v) provisions were made to display PIREP locations (denoted as "*" in the appropriate color) on the map.

LTI values indicating extreme turbulence cause a warning message to be displayed and a keyboard input (carriage return) is required to resume LTIGRAPH program execution. This section of the program was used as supplied, although the threshold for this message is easily changed or omitted.

3.3 Archive Module

The archive module creates and amends the PIREP data file. The PIREP data file is a direct access file which stores the following information about each PIREP: year,

day, time, location (UTM), turbulence category, and aircraft category.

The forecast module's use of the archive module as a data file for current PIREPs has already been discussed. The long-term archival of these data is an equally important function of this module. As discussed previously, one of the primary difficulties in developing any LLT forecast program is lack of data for verification. This module lays the groundwork for future studies by archiving PIREPs; it essentially creates the data base needed for future verification or modification of this forecast module, and the development of others.

3.4 Tutorial Module

The tutorial module was not developed, although it is a necessary part of the complete system. As stated before, this module should support new forecaster training and skill maintenance for experienced forecasters. To that end, it should contain instructions for operation (including examples), and sections on local causes of LLT, LTI background, and local effects (such as the turbulence "climatology" derived by Lester and Burton, 1988).

4. Available Data

4.1 Tower Data.

In order to create and test forecast methods, development of a LLT data base was necessary. Previous investigations at Ft Irwin have been hampered by the lack of data for verification. As noted in Chapter 1, ASL has recently responded to the problem by installing instrumented towers at various sites throughout the reservation (Marrs, 1988). Lester and Burton (1988) have also initiated a PIREP collection program at NTC. These data are now available for development, initialization, and verification of the LLT forecast scheme described in the previous section.

Sensors for ASL's Surface Atmospheric Measuring System (SAMS) were mounted on five 5-meter towers in various locations throughout the Fort Irwin reservation (Figure 3) chosen by ASL on the basis of their proximity to commonly used operations areas, their representation of "average" terrain types, and their accessibility (Marrs, 1988). SAMS is a meteorological data collection system designed and developed for ASL by the New Mexico State University Physical Sciences Laboratory. Each station records pressure, temperature, relative humidity, wind direction, wind speed, peak wind speed, and standard deviation of the wind direction. During the collection period, all

information was transmitted at 15-minute intervals to the base station at BYS.

Printed tower data for the period of interest were manually keyed into a microcomputer spreadsheet program (Quattro, Borland International) for use in the current study. Manual transfer was necessary as prototype system incompatibilities precluded electronic transfer. However, under operational conditions, such data should be ingested automatically.

4.2 PIREPs

As noted previously, Lester and Burton (1988) initiated the collection of PIREPs at NTC. Data were collected over two training periods between 27 February and 12 May 1988, coinciding with the SAMS tower study, and the prevalence of LLT during the spring transition season.

Pilot reports of turbulence were collected after each mission flown during the two cycles. Because of their extensive knowledge of the Ft Irwin terrain (Lester and Burton, 1988), only permanent party pilots were asked to participate in the survey. Each pilot was requested to fill out a short questionnaire after each mission. The pilots were asked to document areas of turbulence encountered along their flight path, including date, time, type of turbulence encountered, and flight level. They were also encouraged to

report areas of no turbulence. See Appendix III for a sample PIREP questionnaire.

A total of 87 PIREP forms were collected and screened for usable information. Of these, approximately 20% were unusable for a variety of reasons (e.g., missing time, date, route; report area too large, etc.) The remaining forms were sorted according to date and time. Multiple reports on the same date were consolidated onto overlays for subsequent analysis. Days with five reports or more, regardless of time of day or turbulence intensity, were selected as case days. A total of 11 days met the criteria (Table 7). Synoptic conditions for these case days have been documented by Incerpi (1989). A total of 19 sets of synoptic data (0000 and/or 1200 GMT) were available for use as inputs to the program (Table 8).

Table 7 PIREP Case Days

Date	Synoptic Description
29 Feb 1988	Pre-Frontal
1 Mar	Post-Frontal
5 Mar	Weak Synoptic Gradient
6 Mar	Weak Synoptic Gradient
22 Apr	Mountain Wave
25 Apr	Mountain Wave
26 Apr	Weak Synoptic Gradient
28 Apr	Pre-Frontal
10 May	Post-Frontal
11 May	Weak Synoptic Gradient
12 May	Weak Synoptic Gradient

Table 8 Synoptic Case Times

	GMT 0000	GMT 1200
29 Feb		x
1 Mar	x	x
2 Mar	x	
5 Mar		x
6 Mar	x	x
7 Mar	x	
22 Apr		x
23 Apr	x	
25 Apr		x
26 Apr	x	x
28 Apr		x
10 May		x
11 May	x	x
12 May	x	x

5. Program Execution and Results

An evaluation of the forecast model is presented below. First, a detailed example of a model run is presented, then model output is compared to observed winds, LTI, and PIREPs for all cases.

5.1 Example of the Program Operation

For purposes of illustration details of the model steps are presented below for a single case: 0000 hrs GMT, 1 March 1988. It should be noted that in actual applications, several intermediate steps discussed here are transparent to the user. Only the inputs and final displays (Appendix IV) are presented on the computer screen.

On this case day, the reservation was under the influence of a high pressure system to the southeast, with post-frontal conditions and moderate southwesterly winds. Table 9 shows the keyboard inputs for the case. These are controlled by the FILEMAKR program, which creates the MAINDATA data file. This data file is accessed by subsequent program elements.

After the FILEMAKR keyboard input module, the WINDMAKR program creates two data files for use in the WOCSS code. Table 10 lists the data in these files. Once these files

Table 9 Keyboard Inputs for 1 Mar 1988, 0000 GMT

Year	1988
Month	3
Date	1
Time (GMT)	0000
Tower 2 Pressure Tendency (mb)	1.0
BYS (Tower 2) Wind Speed (kt)	12
850 mb Wind Speed (kt)	20
850 mb Wind Direction	210
850 mb Temperature (°C)	10
850 mb Height (m)	1495

Tower	1	2	3	4	5
Pressure (mb)	919.5	898.4	892.2	881.0	934.6
Temperature (°F)	61	56	58	54	64
Wind Direction	236	236	202	220	227
Wind Speed (kt)	19	12	16	13	28

Table 10 Wind Model Inputs

5 meter data:

	Tower 1	Tower 2	Tower 3	Tower 4	Tower 5
UTM East	539.6	521.5	547.8	539.5	557.1
UTM North	3898.6	3895.8	3927.5	3920.2	3901.7
Pressure (mb)	919.5	898.4	892.2	881.0	934.6
Temperature (°F)	61	56	58	54	64
Wind Direction	236	236	202	220	227
Wind Speed (kt)	19	12	16	13	28

Vertical structure (Tower 2 values used for surface input, 2000 m values derived as shown in Section 3.2.1):

	Surface (1026 m)	2000 m
UTM East	521.5	521.5
UTM North	3895.8	3895.8
Pressure (mb)	898.4	799.5
Temperature (°C)	13.3	6.4
Wind Direction	236	210
Wind Speed (ms^{-1})	6.2	10.3

are created, the WOCSS model is executed. Anemometer height (10 m) winds are saved and all other output files are deleted. Figure 13 shows model output winds at 10 m. Note the lowest height wind field generated by the WOCSS model is 10 m; these are used as an approximation to the tower (5 m) winds in the LTI program.

Once the horizontal wind field is generated on the 2 km grid, the WINTERP module uses it to interpolate 1 km winds, which are then combined with the resident terrain slope data to derive the w field.

The INDXMAKR routine calculates the macroscale BTI, the $(V+R)_{max}$ normalizing factor (Equation 2), and the raw LTI at each grid point. Figure 14 shows the raw LTI threshold values and 200 m terrain contours. The raw index values range from 35.5 (no turbulence) over the valleys and dry lakebeds, to 111.0 (severe turbulence) over the mountain peaks.

The INDXMOD program adjusts the raw LTI for wake effects and PIREPs, and creates the final LTI data field. Figure 15 shows the wake-modified LTI. As can be seen by comparison with Figure 14, the modifications coincided with areas of large negative terrain slope, near the peaks of the mountain ranges. Note the maximum LTI value has increased to 131.0 (extreme turbulence), but the wake modification has little effect over most of the region.

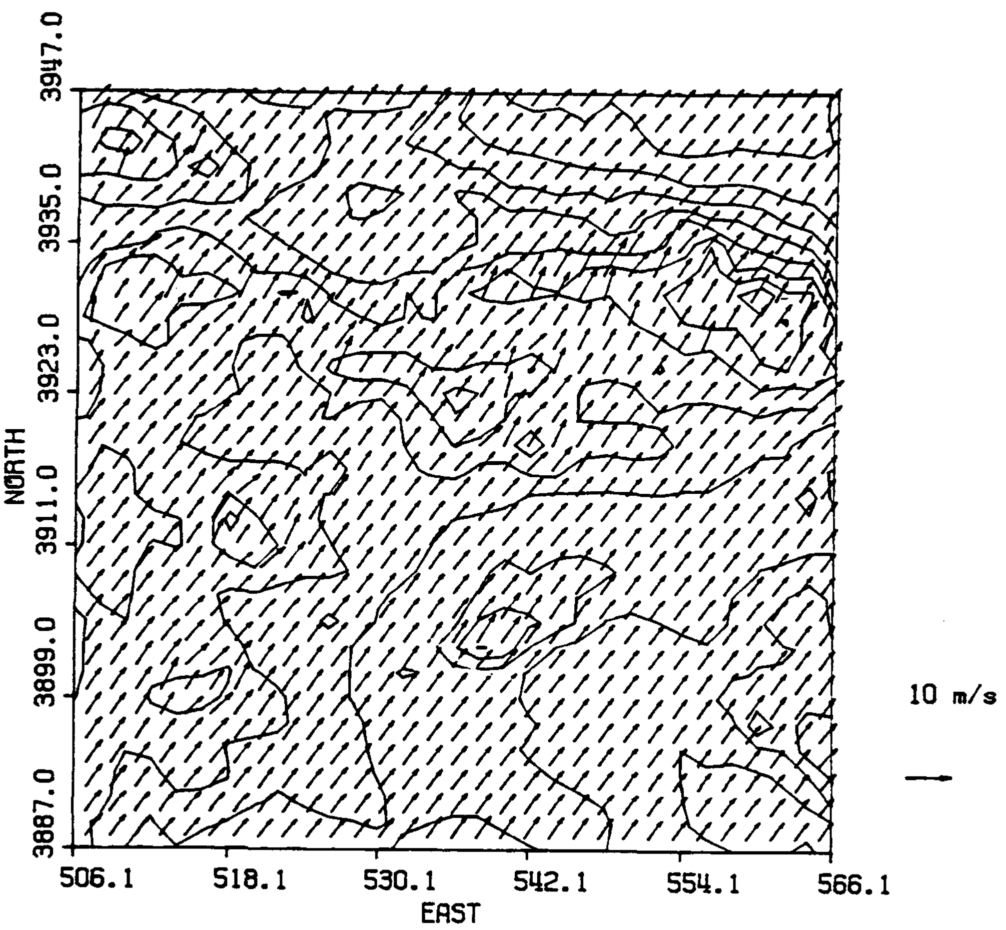

Figure 13 WOCSS Output Tower Winds

10 meter winds generated by the WOCSS model for 0000 GMT 1 March 1988. Arrow at lower right shows scale for 10 ms^{-1} wind.

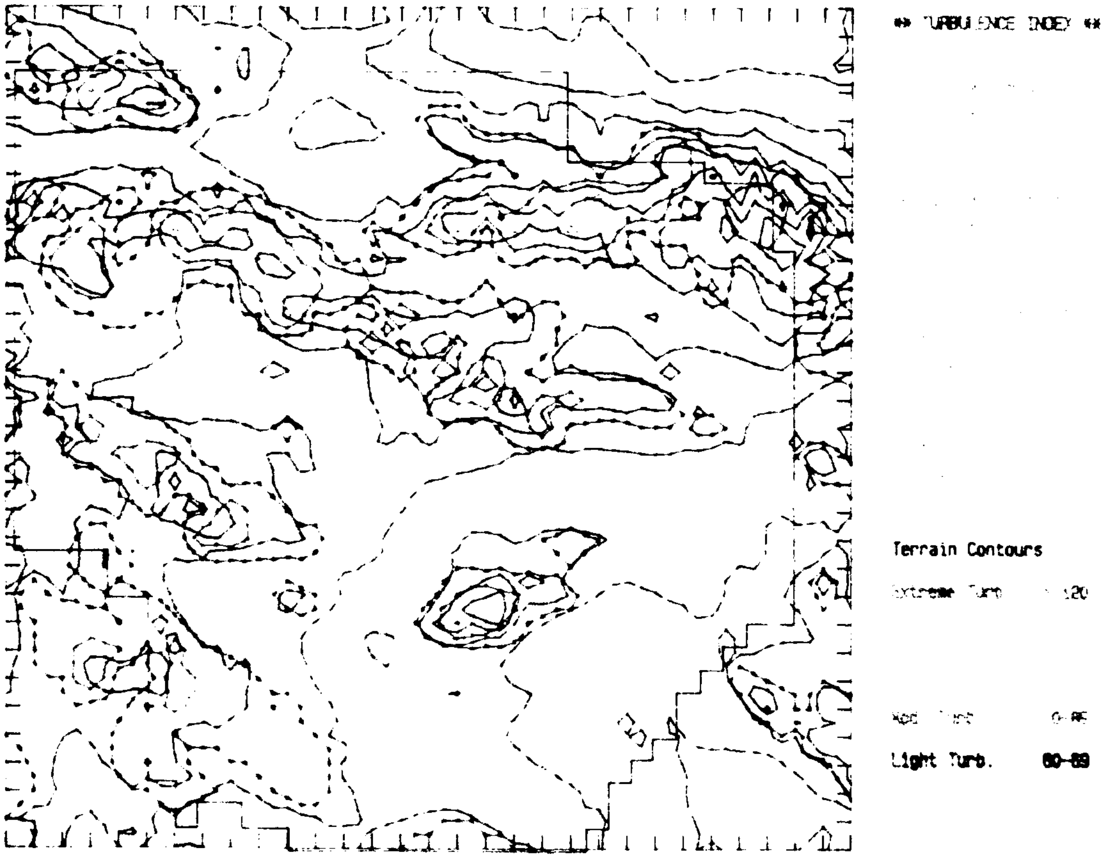

Figure 14 Raw (Unmodified) LTI 200 m terrain contours are shown in brown, outline of NTC in black. LTI turbulence thresh-olds are outlined according to the legend at bottom right. Axes are marked in 2 km increments. North is at the top of the display.

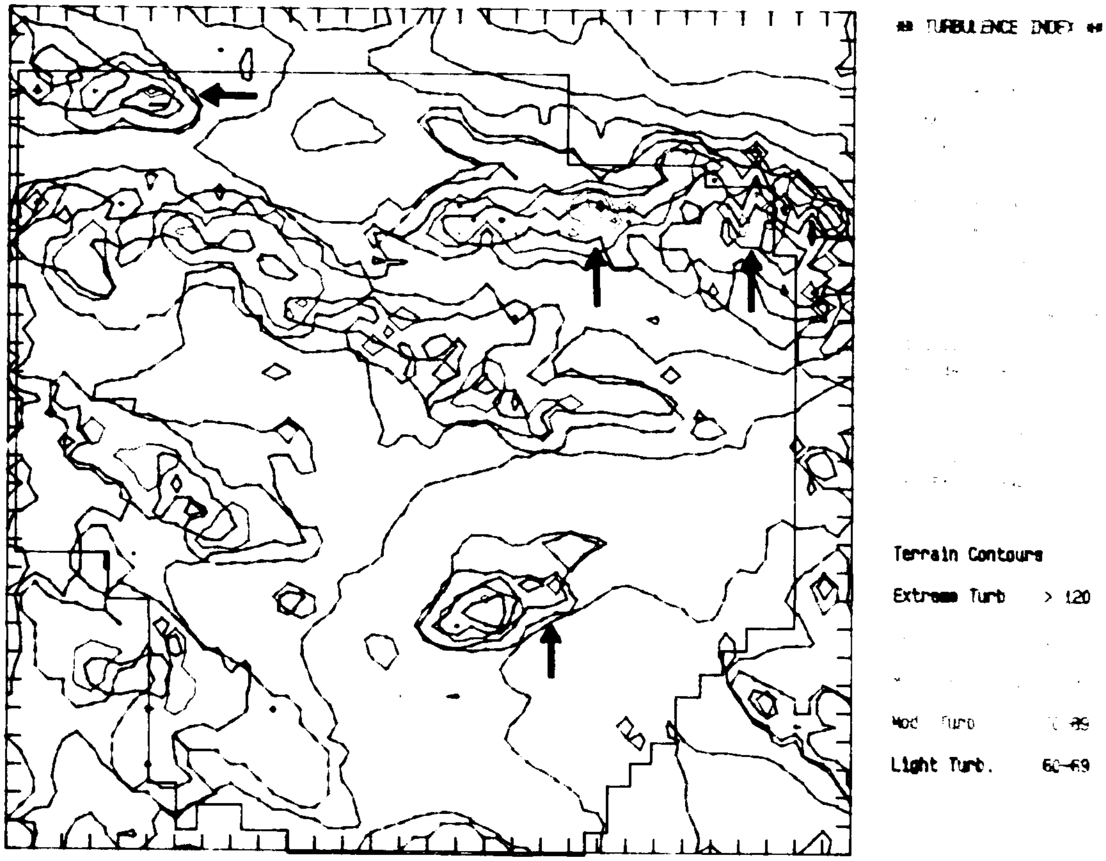

Figure 15 Wake Modified LTI As for Figure 14. Arrows indicate areas of modification.

In order to illustrate the potential impact of the PIREP modification, bogus PIREPs were added based on the turbulence climatology derived by Lester and Burton (1988). These were then used to modify the LTI with the results shown in Figure 16. The bogus PIREPs are indicated by asterisks, and are concentrated in an area 6 km west of BYS (an area of frequent turbulence encounters). Figure 16 shows the extent of the PIREP modification, with many isolated, individual points in the lake beds and valleys being modified to values higher than those in Figure 15. The modifications are more continuous over the mountain ranges. The maximum LTI value has increased to 156.7. Note this was for demonstration only; bogus reports were not used for the actual case tests.

5.2 Program Results

A summary of observed and modelled wind speeds and LTI values is presented in Appendix V. It should be noted that the BTI values for all case days indicated at least moderate/severe turbulence (Table 11). Consequently, if the BTI were the only diagnostic tool for the meteorologist, the post would have been closed to flying in every case. Since BTI has been used widely in the past, this result is interpreted as typical of a large scale turbulence input.

A meaningful evaluation of the LTI program first

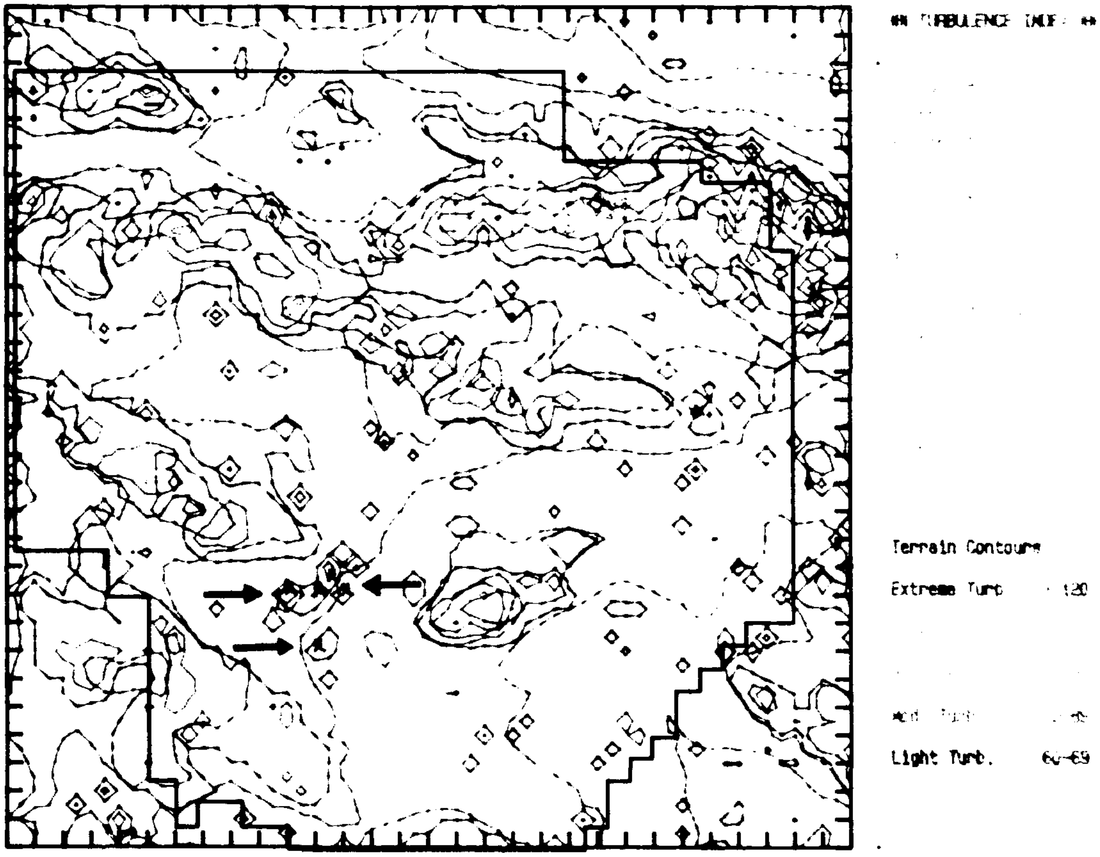

Figure 16 PIREP Modified LTI As for Figure 14. Arrows indicate areas of bogus PIREPs (asterisks).

Table 11 BTI Inputs (R = 59)

DATE/TIME(GMT)	T	V	S	BTI
29 FEB/1200	5	11	27.1	102
01 MAR/0000	10	12	29.9	111
01 MAR/1200	12	6	25.7	103
05 MAR/1200	4	6	24.9	94
06 MAR/0000	18	4	34.3	115
06 MAR/1200	13	9	24.8	106
07 MAR/0000	13	11	33.4	117
22 APR/1200	6	8	30.0	103
23 APR/0000	2	17	35.0	113
25 APR/1200	4	9	24.0	96
26 APR/0000	15	5	35.5	115
26 APR/1200	7	2	32.3	100
28 APR/1200	7	22	29.9	118
10 MAY/1200	1	4	28.6	93
11 MAY/0000	18	3	36.6	117
11 MAY/1200	2	9	31.1	101
12 MAY/0000	17	2	40.6	119
12 MAY/1200	3	4	30.8	97

requires an examination of the wind model. Observed and modelled winds can be compared at the tower sites. This was accomplished statistically, and results are presented in Figure 17 for all 19 cases. The modelled wind speeds (V_M) are related to the observed wind speeds (V_0) as:

$$V_M = 1.09\ V_0 + 1.98\ \mathrm{ms}^{-1} \qquad (3)$$

with a correlation coefficient of 0.70. Equation 3 shows that the model tends to overestimate wind speeds. Figure 17 also shows that there is more scatter at higher wind speeds.[1]

The modelled index (LTI_M) at each of the towers was also compared to the "observed" index (LTI_0), i.e., the value obtained by using the observed tower wind and 1 km grid roughness. These data show a lower correlation than the wind speeds (Figure 18). The least-squares fit equation is:

$$LTI_M = 1.07\ LTI_0 - 4.61 \qquad (4)$$

with a correlation coefficient of .56. It is noted that the model shows a tendency to underestimate at low LTI values and overestimate at higher values, reflecting a similar, though lesser magnitude, tendency in the WOCSS model. While any discrepancy is unfortunate, one may argue that the LTI

[1] Since these tests were run, the WOCSS code has been modified so that winds at grid points nearest the input sites can be constrained to remain as observed (Ludwig, 1990).

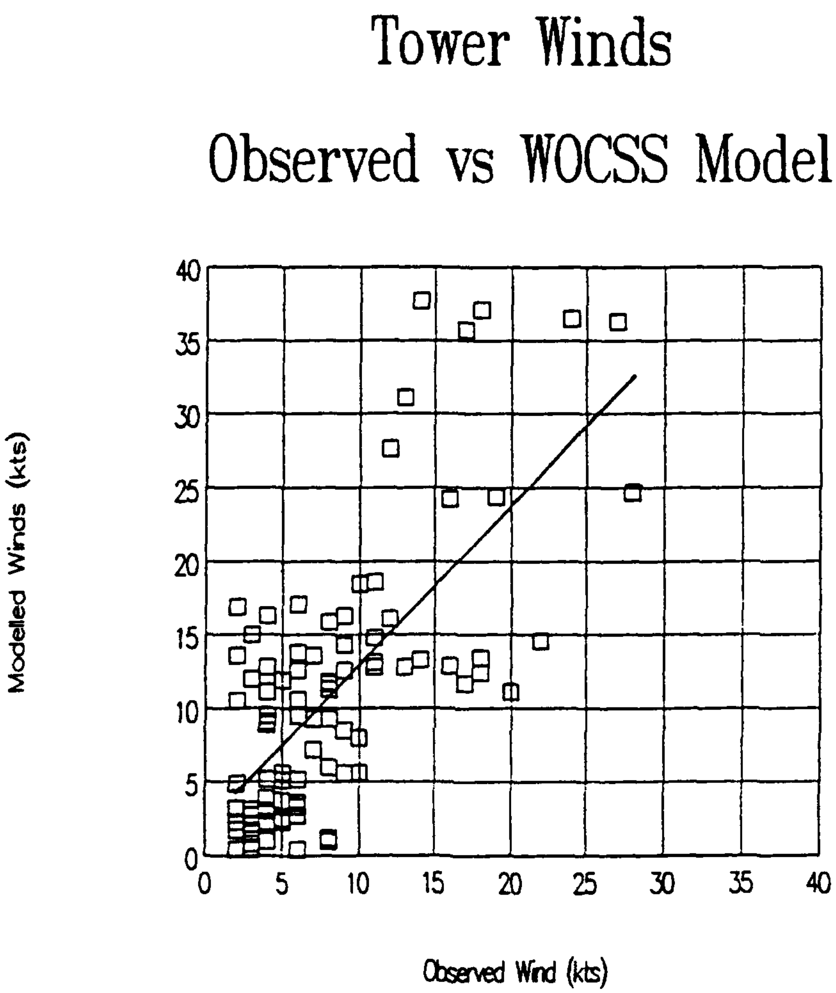

Figure 17 Modelled vs Observed Tower Winds

Line represents least-squares fit.

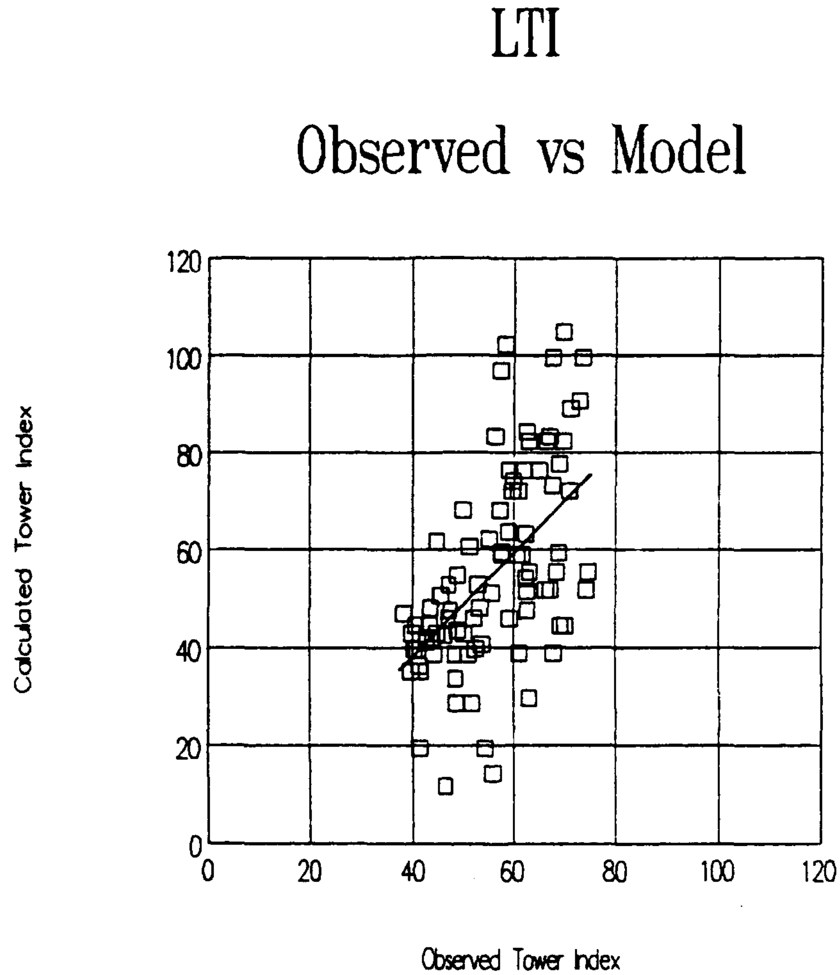

Figure 18 Calculated vs Observed LTI

Line represents least-squares fit.

errs on the side of safety for the higher turbulence categories.

Verifications of LTI turbulence estimates for all cases were made by comparing them with PIREPs as described in the previous chapter. Tables 12 and 13 are contingency tables for raw and wake-modified LTI vs PIREPs for all PIREPs within $\pm$ 1 hr of synoptic times (i.e. case times). Since pilots reported turbulence areas rather than precise locations, LTI values were determined by using the highest turbulence category underlying the reported area (see Appendix III). As summarized in Table 14, the results are nearly identical with and without the wake modification. The model overestimated turbulence categories 52.2% of the time, while underestimating only 4.3%. Again, the errors are on the side of safety.

The model showed better correlations with PIREPs for the 12 hr period following the model run (Tables 15 and 16). Skill scores for the 12 hr forecast were .56 as compared to .29 for the nowcast model.

5.3 Discussion

In general, the LTI overestimates low level turbulence when compared with PIREPs. This overestimation is most likely due to a combination of overestimation by the BTI, by the wind interpolation scheme (already documented), and the nature of the verification scheme (i.e., PIREPs).

Table 12 Contingency Table of Raw LTI vs PIREPs

	OBSERVED					
FORECAST	N	L	M	S	X	TOTAL
N	9	1				10
L	1	1				2
M	1	4				5
S		3	2			5
X		1				1
TOTAL	11	10	2			23

Table 13 Contingency Table of Wake Modified LTI vs PIREPs

OBSERVED

FORECAST	N	L	M	S	X	TOTAL
N	9	1				10
L	1	1				2
M	1	4				5
S		2	2			4
X		2				2
TOTAL	11	10	2			23

Table 14 LTI Nowcast Statistics

	Raw	Wake Modified
Number of Cases	23	23
Total Correct	10	10
% Correct	43.5	43.5
% Overestimate	52.2	52.2
by 1 category	30.4	30.4
by 2 categories	17.4	13.0
by 3 categories	4.3	8.7
% Underestimate	4.3	4.3
Skill[1]	.29	.29

[1] Skill = $\frac{R - E}{T - E}$

R = number of correct forecasts
T = total number of forecasts
E = number of forecasts expected to be correct based on chance

Table 15 Contingency Table of Wake Modified LTI vs 12-hr PIREPs

OBSERVED

FORECAST	N	L	M	S	X	TOTAL
N	33	6	1			40
L	5	14				19
M	5	5	2			12
S	2	1	2			5
X						
TOTAL	45	26	5			76

Table 16 LTI Forecast Statistics

Number of Cases	76
Total Correct	49
% Correct	64.5
% Overforecast	26.3
by 1 category	15.8
by 2 categories	7.9
by 3 categories	2.6
% Underforecast	9.2
by 1 category	7.9
by 2 categories	1.3
Skill	.56

An attempt to compensate for the BTI's tendency to overestimate turbulence categories was made by using near-surface winds instead of the gradient winds which were used in the original scheme. Even so, the BTI values for all case days were in excess of the threshold of 90 required for severe turbulence. This may indicate that the turbulence category thresholds, which were originally derived for fixed-wing light aircraft over large-scale areas, should be adjusted for helicopters and/or the local terrain. That aircraft were allowed to fly at all is indicative of the lack of confidence in macro scale indices.

The WOCSS wind interpolation scheme showed a tendency to overestimate wind speeds, a trait which may be attributed to several causes. The original model was designed for use in less complex terrain than is encountered at NTC, and might not handle the extremely rough terrain encountered there. Additionally, the number of towers and their locations are less than optimum; they may provide unrepresentative data. More towers will provide more input data, and presumably a better model.

Finally, more data are needed for verification. Too few PIREPs were available for a statistically meaningful test of the LTI algorithm. Also, in many cases, the areas marked on the PIREP questionnaires were obvious overestimates of the actual observation area (i.e., the circle on the map was too large). Consequently, the area

reported may cover areas of high LTI which were not actually overflown. The problem of the subjective nature of the PIREPs has already been addressed.

The model performed better "forecasting" LLT in the 12 hours following the model run than it did in describing the current situation. As the preponderance of PIREPs occurred between 1200 and 2359 GMT, the normal diurnal increase in wind speed (mechanical turbulence) and thermal turbulence may have offset the tendency toward over-forecasts in the 1200 GMT model run.

6. Conclusions and Recommendations

6.1 Conclusions

The Local Turbulence Index (LTI) was applied as an objective measure of turbulence intensity at 1 km intervals across NTC. LTI fields showed unambiguous gradients in turbulence intensity across Ft Irwin. Typical analyses which showed severe turbulence over the rugged hills in the northern portion of the post showed lower intensities over the broad valleys to the south.

Two modifications to the original formulations developed by Burton (1964), and Lester and Burton (1988) were introduced. In the first, turbulence areas delineated by certain critical LTI values were enlarged in the presence of "turbulent wakes" which were functions of the local wind velocity and the slope and orientation of the local terrain. The areal impact of modification was small because the scales of the wakes are small compared to the analysis grid and/or because the threshold vertical velocity used to define the wake was too large. Further study and verification is necessary.

In the second modification, turbulence reports (PIREPs) taken within one hour of the LTI analysis were assigned an LTI value representative of the reported intensity. Subsequently, the slope and orientation of the terrain was

used to identify "similar" locations across NTC; the LTI at the latter points were modified to the same degree as the initial point. The areal impact of this modification was significant. However, there was some question as to the reality of the pattern (i.e., many small, closed "turbulent" regions appeared across the domain). It is suggested that the addition of terrain height and local wind velocity to terrain slope and orientation would be more useful in the search for "similar" locations. Further verification with more and better PIREPs is needed.

The algorithm developed here is a useful nowcast/forecast system for LLT not associated with moist convection. It meets the definitions of an "expert system" presented in Chapter 2. It yields a consistent product, eliminating forecaster bias and bringing all forecasters to a similar experience level. The forecaster need not be familiar with the local terrain or conditions in order to provide reasonably accurate forecasts of LLT. The use of a numerical index eliminates the subjectivity associated with descriptive categories and allows the effective use of statistics in the verification and improvement of the program.

The system is operationally oriented and is designed for use on the type of microcomputer commonly found in forecast offices. It requires minimal operator inputs, with the exception of the tower data. The time required to

execute the model is on the order of 10 minutes, with most of that time being spent on wind model computations (i.e., forecaster "hands off" time).

The LTI's usefulness as an operational LLT forecast tool is the result of several characteristics. The index successfully resolves the conflict in scale between point (mesoscale) warnings issued for the area and the microscale environment at Ft Irwin. Whereas the BTI values for all case days were in excess of the threshold of 90 required for severe turbulence, the LTI indicated that the severe turbulence was usually confined to small areas over the mountain tops. The LTI showed, and PIREPs verified, the absence of severe turbulence over most of the reservation, emphasizing the inadequacy of a point warning approach.

The graphic display of the LTI field is the ideal way to present these data for interpretation. The usefulness of the display is limited, however, by the lack of a paper copy backup to facilitate pilot briefings and provide a permanent record of the program output.

The comparison of the model as a forecast and nowcast aid with observations illustrates its utility, as well as its tendency to overestimate turbulence intensity. This overestimation could result from a number of sources, including the wind model, the scaling procedure (Equation 2), modification procedures, and the LTI turbulence category threshold values.

The archive module, if properly maintained, will prove extremely valuable for future investigations of LLT at Ft Irwin by providing a comprehensive data base of turbulence observations.

6.2 Recommendations

Recommendations for further study and development of the program fall into three categories: (i) improvements to execution of the current program, (ii) improvements to the forecast methodology, and (iii) improved applications. Of these, the improvements to program execution can be realized most rapidly.

Short term improvements will reduce the workload on the forecaster and improve the display of the final index. For example, a subroutine to read the tower data directly from the base station computer is required, and to this end the section is isolated in the code. As stated in the previous section, a paper copy of the final output field will be beneficial. The illustrations of the screen display presented here were plotted on a Hewlett-Packard HP 7475A plotter; however plot times were on the order of 30-45 minutes. An operational forecaster would not have that much time. The alternative is to use a dot matrix printer, but this poses the problem of superimposing many different contours in black and white. A possible solution would be

to contour the terrain and only one critical LTI threshold, indicating fly/no fly areas.

More data are needed for testing and modification of this and other LLT forecast systems, both at Ft Irwin and in other areas. To this end, a major effort should be made to gather quantitative turbulence data, such as that provided by aircraft-borne accelerometers, although the PIREP data base should not be neglected. Improvements to the forecast methodology will also have to wait for a larger turbulence data base.

Clearly, the accuracy of the wind interpolation scheme plays a major role in determining the accuracy of the LTI. As has been discussed, numerous wind models are available. Operationally, a compromise must be made between speed (i.e., model simplicity) and accuracy. A simpler model might be able to interpolate winds to the full 61 x 61 grid, which may be more accurate in the long run as it would eliminate linear interpolation on the 31 x 31 grid. The assumptions made in the vertical structure inputs to the WOCSS model might also be avoided with a simpler model.

A review of the LTI wake and PIREP modification routines in the light of a larger turbulence data bases holds promise for great improvements. The wake and PIREP modifications both involved arbitrary decisions based on research and past experience which should be examined in the light of future data. The wake modification may be more

appropriately applied at a different vertical velocity threshold, or perhaps in conjunction with other parameters such as distance from major ridgelines, stability, etc. Also the actual modification might be better applied as a percentage change in the index (as in the PIREP case).

Another weak link in the PIREP modification scheme is in the determination of where else to apply the modification. Different terrain parameters should be examined for use as selection criteria. Also, other modifications should be considered, such as the inclusion of a low level wind shear parameterization.

Other aspects of this program that should be examined further with respect to its application include validity of turbulence category thresholds for the LTI, flight levels for which the index is valid, and "transportability" to other areas. The question of appropriate terrain scale, and hence model grid spacing, should also be addressed. The answer will likely involve a compromise between optimum resolution and cost (in terms of both time and computer power).

The LLT nowcast/forecast program presented is a useful tool which can be used in its current configuration, and can be improved with the development of a larger PIREP data base. It is the author's hope that the program will serve as a foundation for future studies.

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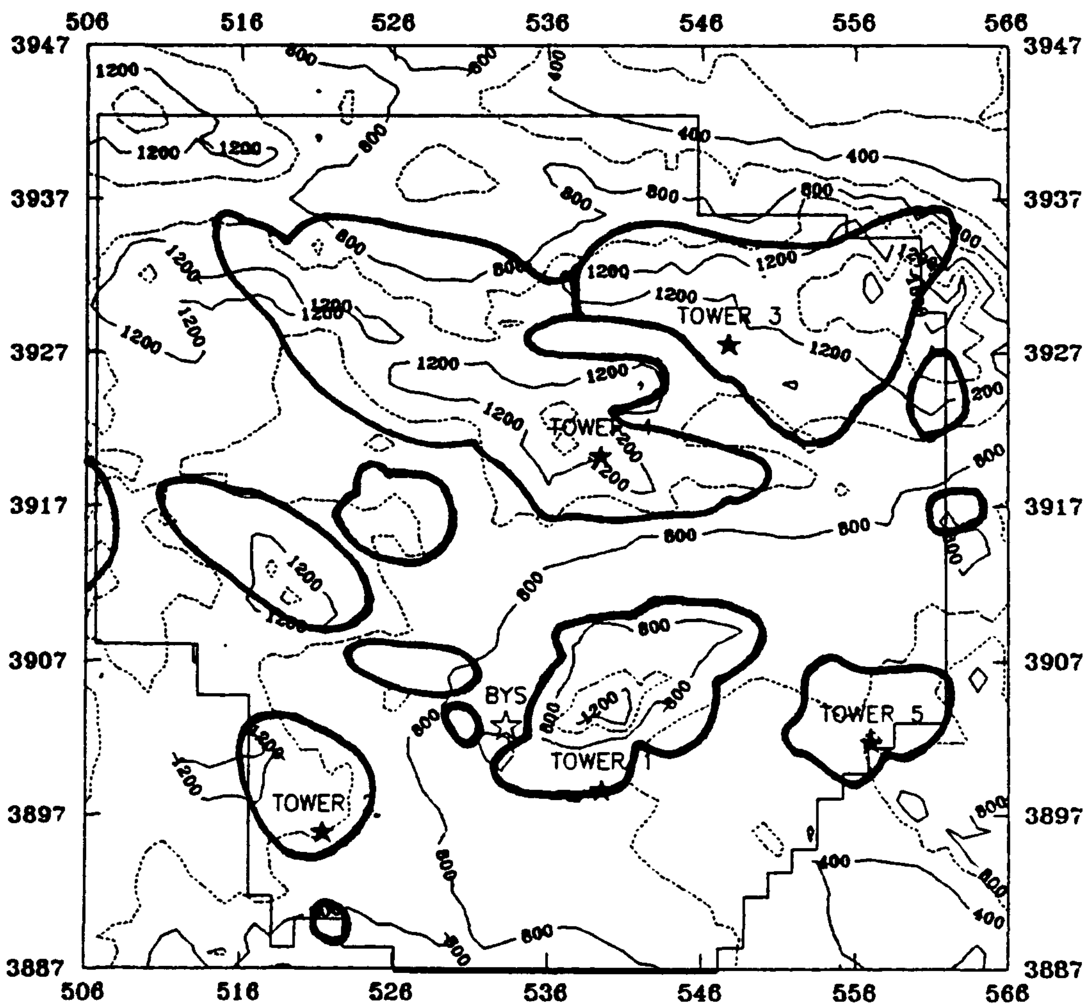
APPENDIX I: Turbulence-Prone Areas at Ft Irwin

The map, redrawn from Lester and Burton (1988), outlines turbulence prone areas of Ft Irwin. It is part of the turbulence "climatology" derived from interviews with permanent party pilots stationed at Ft Irwin. For more detailed descriptions of the areas see Lester and Burton (1988).

Turbulence–Prone Areas



APPENDIX II: Source code listings for LTI Archive and Forecast modules.

```
      PROGRAM ARCHIV
C     ------------------------------------------
C     THIS PROGRAM LOADS PILOT REPORTS INTO THE PIREP.DAT
C     DATA FILE.
C     ------------------------------------------
      CHARACTER INTENS, ANS
      INTEGER CDAY,ACCAT
      REAL MONTH
      LOGICAL THERE
      CALL CLEAR
      WRITE(*,*)'Please answer the following questions about
     ,
      WRITE(*,*)'the turbulence incident: '
      WRITE(*,*)
      WRITE(*,*)
200   WRITE(*,*)'What was the YEAR (GMT, four digits)? '
      READ(*,*)YEAR
      WRITE(*,*)
      IF(YEAR.LT.1988.)THEN
       WRITE(*,3)
       GO TO 200
      ENDIF
201   WRITE(*,*)'What was the MONTH (GMT, two digits)? '
      READ(*,*)MONTH
      WRITE(*,*)
      IF((MONTH.GT.12.).OR.(MONTH.LT.1.))THEN
       WRITE(*,3)
       GO TO 201
      ENDIF
202   WRITE(*,*)'What was the DATE (GMT, two digits)? '
      READ(*,*)DAY
      WRITE(*,*)
      IF((DAY.LT.1.).OR.(DAY.GT.31.))THEN
       WRITE(*,3)
       GO TO 202
      ENDIF
      CALL DATE(DAY,MONTH,YEAR,CDAY)
203   WRITE(*,*)'What was the TIME (GMT, four digits)? '
      READ(*,*)TIME
      WRITE(*,*)
      IF((TIME.LT.0.).OR.(TIME.GT.2359.))THEN
       WRITE(*,3)
       GO TO 203
      ENDIF
204   WRITE(*,*)'Enter the UTM COORDINATES in km. '
      WRITE(*,*)
      WRITE(*,*)'                                     NORTH: '
      READ (*,*) y
      WRITE(*,*)
      WRITE(*,*)'                                      EAST: '
      READ (*,*) x
```

```
      WRITE(*,*)
      IF((Y.LT.3887.).OR.(Y.GT.3947.).OR.(X.LT.506.1).OR.
     +    (X.GT.566.1))THEN
       WRITE(*,3)
       GO TO 204
      ENDIF
205   WRITE(*,*)'What was the reported TURBULENCE INTENSITY?
'
      WRITE(*,*)' L / M / S / X '
      READ (*,2) INTENS
      WRITE(*,*)
      IF((INTENS.NE.'L').AND.(INTENS.NE.'l'))THEN
       IF((INTENS.NE.'M').AND.(INTENS.NE.'m'))THEN
           IF((INTENS.NE.'S').AND.(INTENS.NE.'s'))THEN
            IF((INTENS.NE.'X').AND.(INTENS.NE.'x'))THEN
                 WRITE(*,3)
                 GO TO 205
              ENDIF
            ENDIF
       ENDIF
      ENDIF
206   WRITE(*,*)'What was the AIRCRAFT CATEGORY? (1,2,3) '
      READ (*,*) ACCAT
      WRITE(*,*)
      IF((ACCAT.LT.1).OR.(ACCAT.GT.3))THEN
       WRITE(*,3)
       GO TO 206
      ENDIF
      CALL CLEAR
C     **********************************
C     ERRROR CHECK
C     **********************************
      WRITE(*,*)'You have entered the following values:'
      WRITE(*,4) YEAR
      WRITE(*,5) MONTH
      WRITE(*,6) DAY
      WRITE(*,7) TIME
      WRITE(*,8) Y
      WRITE(*,9) X
      WRITE(*,20) INTENS
      WRITE(*,21) ACCAT
      WRITE(*,*)
      WRITE(*,*) 'Press "RETURN" to continue, "U" to update
values '
      READ(*,2)ANS
      IF((ANS.EQ.'u').OR.(ANS.EQ.'U'))THEN
       CALL CLEAR
       GO TO 200
      ENDIF
C     **********************************
C     CHECK FOR PIREP FILE
```

```
C     **********************************
      INQUIRE(FILE='PIREP.DAT', EXIST = THERE)
      IF(.NOT.THERE) CALL MPRP
C     **********************************
C     OPEN PIREP FILE AND READ NUMBER OF RECORDS
C     **********************************
      OPEN(10,FILE='PIREP.DAT',ACCESS='DIRECT',STATUS='OLD',
     +         FORM='FORMATTED', RECL=50)
      ICOUNT=0
      DO 10, I=1,999
       READ(10,101,REC=I,END=11) CHECK
      ICOUNT=ICOUNT+1
 10   CONTINUE
 11   IC=ICOUNT+1
C     **********************************
C     WRITE TO FILE
C     **********************************
      WRITE(10,100,REC=IC)YEAR,CDAY,TIME,X,Y,INTENS,ACCAT
      CLOSE(10)
C     **********************************
C     CHECK FOR MORE REPORTS
C     **********************************
      CALL CLEAR
      WRITE(*,*)'Do you wish to record another PIREP? (Y/N)
     '
      READ (*,2) REPLY
      IF((REPLY.EQ.'N').OR.(REPLY.EQ.'n'))GO TO 9999
      GO TO 200
 2    FORMAT(A1)
 3    FORMAT(1X,'INPUT BEYOND LIMITS',/)
 4    FORMAT(1X,'        Year: ',F5.0)
 5    FORMAT(1X,'       Month: ',F3.0)
 6    FORMAT(1X,'         Day: ',F3.0)
 7    FORMAT(1X,'        Time: ',F5.0)
 8    FORMAT(1X,'    Location:',F7.1,' north')
 9    FORMAT(1X,'             ',F6.1,' east')
 20   FORMAT(1X,'   Intensity: ',A1)
 21   FORMAT(1X,'A/C Category: ',I1)
 100  FORMAT(1X,F6.0,2X,I3,F6.0,2X,2(F11.1,2X),A1,2X,I1)
 101  FORMAT(F6.0)
 9999 END
C
C
C     -----------------------------------------------------
      SUBROUTINE CLEAR
C     -----------------------------------------------------
C
C     **********************************
C     SUBROUTINE TO CLEAR THE SCREEN
C     **********************************
      DO 10, I=1,30
```

```
       WRITE(*,*)
 10   CONTINUE
      RETURN
      END
C
C
C     ---------------------------------------------------
      SUBROUTINE DATE(DAY,MONTH,YEAR,CDAY)
C     ---------------------------------------------------
C
C     *********************************
C     THIS S/R CALCULATES JULIAN (CALENDAR) DATES FROM DAY,
MONTH,
C     YEAR VALUES AND WAS DEVELOPED BY F.D. BARLOW (BARLOW,
1980,
C     'SOLAR ENERGY' 25, P479).  MODIFICATIONS BY N.L.
SMITH, 1988.
C     *********************************
      REAL DAY,MONTH,YEAR
      INTEGER CDAY
      YRES = AMOD(YEAR,4.0)
      CRES = AMOD(YEAR,100.0)
      FACTOR = 32.8
      IF (YRES.EQ.0.0.AND.CRES.NE.0.0)FACTOR = 31.8
      IF (MONTH.LE.2.0)FACTOR = 30.6
      CDAY = INT(30.6*MONTH+DAY-FACTOR+.5)
      RETURN
      END
C
C
C     ----------------------------------------------------
      SUBROUTINE MPRP
C     ----------------------------------------------------
C     INITIALIZES PIREP FILE
C     ----------------------------------------------------
      CHARACTER INTENS
      OPEN(10,FILE='PIREP.DAT',ACCESS='DIRECT',STATUS='NEW',
     +         FORM='FORMATTED', RECL=50)
      YEAR=9999.
      IDAY=999
      TIME=999.9
      X=99999.9
      Y=999999.9
      INTENS='Z'
      ICCAT=9
      WRITE(10,100,REC=1)YEAR,IDAY,TIME,X,Y,INTENS,ICCAT
 100  FORMAT(1X,F6.0,2X,I3,F6.0,2X,2(F11.1,2X),A1,2X,I1)
      CLOSE(10)
      RETURN
      END
```

```
      PROGRAM FILEMAKR
C     **********************************
C     CREATES DATA FILE FOR USE WITH LLT FORECAST AID
C     **********************************
      CHARACTER ANS
      INTEGER CDAY,TIME
      REAL DAY,MONTH,YEAR,LAPSE
      REAL TPRES(5),TTEMP(5),TDIR(5),TVEL(5),M2FT
      CALL CLEAR
200   WRITE(*,*)'What is the YEAR (GMT, four digits)? '
      READ(*,*)YEAR
      WRITE(*,*)
      IF(YEAR.LT.1988.)THEN
       WRITE(*,3)
       GO TO 200
      ENDIF
201   WRITE(*,*)'What is the MONTH (GMT, two digits)? '
      READ(*,*)MONTH
      WRITE(*,*)
      IF((MONTH.GT.12.).OR.(MONTH.LT.1.))THEN
       WRITE(*,3)
       GO TO 201
      ENDIF
202   WRITE(*,*)'What is the DATE (GMT, two digits)? '
      READ(*,*)DAY
      WRITE(*,*)
      IF((DAY.LT.1.).OR.(DAY.GT.31.))THEN
       WRITE(*,3)
       GO TO 202
      ENDIF
      CALL DATE(DAY,MONTH,YEAR,CDAY)
      WRITE(*,*)'What is the TIME (GMT, four digits)? '
      READ(*,*)TIME
      WRITE(*,*)
203   IF((TIME.LT.0.).OR.(TIME.GT.2359.))THEN
       WRITE(*,3)
       GO TO 203
      ENDIF
      WRITE(*,*)'What is the three-hour pressure change (mb)
? '
      READ (*,*) APP
      WRITE(*,*)
      WRITE(*,*)'What is the surface wind speed in knots? '
      READ (*,*) BYSWIND
      WRITE(*,*)
      CALL CLEAR
      WRITE(*,*)'You have entered the following values: '
      WRITE(*,*)
      WRITE(*,4) YEAR
      WRITE(*,5) MONTH
      WRITE(*,6) DAY
```

```
      WRITE(*,7) TIME
      WRITE(*,8) APP
      WRITE(*,9) BYSWIND
      WRITE(*,*)
      WRITE(*,*) 'Press "RETURN" to continue, "U" to update
values '
      READ(*,2)ANS
      IF((ANS.EQ.'u').OR.(ANS.EQ.'U'))THEN
       CALL CLEAR
       GO TO 200
      ENDIF
      CALL CLEAR
204   WRITE(*,*)'For 850 mb, what is the'
      WRITE(*,*)
      WRITE(*,*)'Wind speed   (knots) ? '
      READ (*,*) UAVEL
      WRITE(*,*)
      WRITE(*,*)'Wind direction (deg) ? '
      READ (*,*) UADIR
      WRITE(*,*)
      WRITE(*,*)'Temperature (deg C) ? '
      READ (*,*) UATEMP
      WRITE(*,*)
      WRITE(*,*)'Height (meters) ? '
      READ (*,*) UAHT
      WRITE(*,*)
      CALL CLEAR
      WRITE(*,*)'You have entered the following values for
850 mb: '
      WRITE(*,*)
      WRITE(*,10) UAVEL
      WRITE(*,11) UADIR
      WRITE(*,12) UATEMP
      WRITE(*,13) UAHT
      WRITE(*,*)
      WRITE(*,*) 'Press "RETURN" to continue, "U" to update
values '
      READ(*,2)ANS
      IF((ANS.EQ.'u').OR.(ANS.EQ.'U'))THEN
       CALL CLEAR
       GO TO 204
      ENDIF
      CALL CLEAR
C     **********************************
C     BEGIN TOWER INPUT
C     **********************************
      CALL CLEAR
205   WRITE(*,*)'What is the PRESSURE (in mb) at Tower 1 ? '
      READ (*,*) TPRES(1)
      WRITE(*,*)
```

```
      WRITE(*,*)'What is the TEMPERATURE (in °F) at Tower 1
? '
      READ (*,*) TTEMP(1)
      WRITE(*,*)
      WRITE(*,*)'What is the wind DIRECTION (in °) at Tower
1 ? '
      READ (*,*) TDIR(1)
      WRITE(*,*)
      WRITE(*,*)'What is the wind VELOCITY at Tower 1 ? '
      READ (*,*) TVEL(1)
      CALL CLEAR
      WRITE(*,*)'You have entered the following values for
Tower 1: '
      WRITE(*,*)
      WRITE(*,14) TPRES(1)
      WRITE(*,15) TTEMP(1)
      WRITE(*,11) TDIR(1)
      WRITE(*,10) TVEL(1)
      WRITE(*,*)
      WRITE(*,*) 'Press "RETURN" to continue, "U" to update
values '
      READ(*,2)ANS
      IF((ANS.EQ.'u').OR.(ANS.EQ.'U'))THEN
       CALL CLEAR
       GO TO 205
      ENDIF
      CALL CLEAR
 206  WRITE(*,*)'What is the PRESSURE (in mb) at Tower 2 ? '
      READ (*,*) TPRES(2)
      WRITE(*,*)
      WRITE(*,*)'What is the TEMPERATURE (in °F) at Tower 2
? '
      READ (*,*) TTEMP(2)
      WRITE(*,*)
      WRITE(*,*)'What is the wind DIRECTION (in °) at Tower
2 ? '
      READ (*,*) TDIR(2)
      WRITE(*,*)
      WRITE(*,*)'What is the wind VELOCITY at Tower 2 ? '
      READ (*,*) TVEL(2)
      CALL CLEAR
      WRITE(*,*)'You have entered the following values for
Tower 2: '
      WRITE(*,*)
      WRITE(*,14) TPRES(2)
      WRITE(*,15) TTEMP(2)
      WRITE(*,11) TDIR(2)
      WRITE(*,10) TVEL(2)
      WRITE(*,*)
      WRITE(*,*) 'Press "RETURN" to continue, "U" to update
values '
```

```
      READ(*,2)ANS
      IF((ANS.EQ.'u').OR.(ANS.EQ.'U'))THEN
       CALL CLEAR
       GO TO 206
      ENDIF
      CALL CLEAR
207   WRITE(*,*)'What is the PRESSURE (in mb) at Tower 3 ? '
      READ (*,*) TPRES(3)
      WRITE(*,*)
      WRITE(*,*)'What is the TEMPERATURE (in °F) at Tower 3
? '
      READ (*,*) TTEMP(3)
      WRITE(*,*)
      WRITE(*,*)'What is the wind DIRECTION (in °) at Tower
3 ? '
      READ (*,*) TDIR(3)
      WRITE(*,*)
      WRITE(*,*)'What is the wind VELOCITY at Tower 3 ? '
      READ (*,*) TVEL(3)
      CALL CLEAR
      WRITE(*,*)'You have entered the following values for
Tower 3: '
      WRITE(*,*)
      WRITE(*,14) TPRES(3)
      WRITE(*,15) TTEMP(3)
      WRITE(*,11) TDIR(3)
      WRITE(*,10) TVEL(3)
      WRITE(*,*)
      WRITE(*,*) 'Press "RETURN" to continue, "U" to update
values '
      READ(*,2)ANS
      IF((ANS.EQ.'u').OR.(ANS.EQ.'U'))THEN
       CALL CLEAR
       GO TO 207
      ENDIF
      CALL CLEAR
208   WRITE(*,*)'What is the PRESSURE (in mb) at Tower 4 ? '
      READ (*,*) TPRES(4)
      WRITE(*,*)
      WRITE(*,*)'What is the TEMPERATURE (in °F) at Tower 4
? '
      READ (*,*) TTEMP(4)
      WRITE(*,*)
      WRITE(*,*)'What is the wind DIRECTION (in °) at Tower
4 ? '
      READ (*,*) TDIR(4)
      WRITE(*,*)
      WRITE(*,*)'What is the wind VELOCITY at Tower 4 ? '
      READ (*,*) TVEL(4)
      CALL CLEAR
```

```
      WRITE(*,*)'You have entered the following values for
Tower 4: '
      WRITE(*,*)
      WRITE(*,14) TPRES(4)
      WRITE(*,15) TTEMP(4)
      WRITE(*,11) TDIR(4)
      WRITE(*,10) TVEL(4)
      WRITE(*,*)
      WRITE(*,*) 'Press "RETURN" to continue, "U" to update
values '
      READ(*,2)ANS
      IF((ANS.EQ.'u').OR.(ANS.EQ.'U'))THEN
       CALL CLEAR
       GO TO 208
      ENDIF
      CALL CLEAR
209   WRITE(*,*)'What is the PRESSURE (in mb) at Tower 5 ? '
      READ (*,*) TPRES(5)
      WRITE(*,*)
      WRITE(*,*)'What is the TEMPERATURE (in °F) at Tower 5
? '
      READ (*,*) TTEMP(5)
      WRITE(*,*)
      WRITE(*,*)'What is the wind DIRECTION (in °) at Tower
5 ? '
      READ (*,*) TDIR(5)
      WRITE(*,*)
      WRITE(*,*)'What is the wind VELOCITY at Tower 5 ? '
      READ (*,*) TVEL(5)
      CALL CLEAR
      WRITE(*,*)'You have entered the following values for
Tower 5: '
      WRITE(*,*)
      WRITE(*,14) TPRES(5)
      WRITE(*,15) TTEMP(5)
      WRITE(*,11) TDIR(5)
      WRITE(*,10) TVEL(5)
      WRITE(*,*)
      WRITE(*,*) 'Press "RETURN" to continue, "U" to update
values '
      READ(*,2)ANS
      IF((ANS.EQ.'u').OR.(ANS.EQ.'U'))THEN
       CALL CLEAR
       GO TO 209
      ENDIF
      CALL CLEAR
C     ***********************************
C     CALCULATE LAPSE RATE (DEG C PER 1000 FT)
C     ***********************************
      M2FT = 3.2808399
      DT = TTEMP(2) - UATEMP
```

```
      DZ = (UAHT - 1026) * M2FT
      LAPSE = ABS(DT/DZ * 1000)
      APP = 10 * ABS(APP)
C     **********************************
C     OPEN FILE AND WRITE DATA
C     **********************************
      OPEN (UNIT = 10,
     +        FILE = 'MAINDATA.DAT',
     +        ACCESS = 'DIRECT',
     +        STATUS = 'NEW',
     +        FORM = 'FORMATTED',
     +        RECL = 10)
      WRITE(10,2000,REC=1)YEAR
      WRITE(10,1000,REC=2)CDAY
      WRITE(10,1000,REC=3)TIME
      WRITE(10,2000,REC=4)APP
      WRITE(10,2000,REC=5)BYSWIND
      WRITE(10,2000,REC=6)UAVEL
      WRITE(10,2000,REC=7)UADIR
      WRITE(10,2000,REC=8)UATEMP
      WRITE(10,2000,REC=9)UAHT
      WRITE(10,2000,REC=10)LAPSE
      DO 40, I=1,5
       WRITE(10,2000,REC=(10+I))TPRES(I)
       WRITE(10,2000,REC=(15+I))TTEMP(I)
       WRITE(10,2000,REC=(20+I))TDIR(I)
       WRITE(10,2000,REC=(25+I))TVEL(I)
 40   CONTINUE
 2    FORMAT(A1)
 3    FORMAT(1X,'INPUT BEYOND LIMITS',/)
 4    FORMAT(1X,'          Year: ',F5.0,' GMT')
 5    FORMAT(1X,'         Month: ',F3.0,' GMT')
 6    FORMAT(1X,'           Day: ',F3.0,' GMT')
 7    FORMAT(1X,'          Time: ',I4,' GMT')
 8    FORMAT(1X,'           APP: ',F4.1,' mb')
 9    FORMAT(1X,' Suface Wind: ',F5.1,' kts')
 10   FORMAT(1X,'    Wind Speed: ',F5.1,' knots')
 11   FORMAT(1X,'Wind Direction: ',F5.1,' °')
 12   FORMAT(1X,'   Temperature: ',F5.1,' °C')
 13   FORMAT(1X,'        Height: ',F7.1,' meters')
 14   FORMAT(1X,'      Pressure: ',F6.1,' mb')
 15   FORMAT(1X,'   Temperature: ',F4.1,' °F')
 1000 FORMAT(I4)
 2000 FORMAT(F7.1)
      END

C     -----------------------------------------------------
      SUBROUTINE CLEAR
C     -----------------------------------------------------
C
```

```
C      **********************************
C      THIS S/R CLEARS THE SCREEN
C      **********************************
       DO 10, I=1,30
        WRITE(*,*)' '
 10    CONTINUE
       RETURN
       END
C
```

```
      PROGRAM WINDMAKR
C     **********************************
C     THIS PROGRAM READS DIRECT ACCESS FILES CREATED BY
C     'FILEMAKR' AND CREATES INPUT FILES FOR THE WOCSS WIND
C     MODEL.
C     **********************************
      INTEGER CDAY, IYEAR, ITIME, JT(5)
      REAL YEAR, TIME, XS(5), YS(5), LAPSE
      REAL TPRES(5),TTEMP(5),TDIR(5),TVEL(5)
      REAL UAHT, UATEMP, UADIR, UAVEL
      OPEN(UNIT = 10,
     +       FILE = 'MAINDATA.DAT',
     +       ACCESS = 'DIRECT',
     +       STATUS = 'OLD',
     +       FORM = 'FORMATTED',
     +       RECL = 10)
      READ(10,2000,REC=1) YEAR
      READ(10,1000,REC=2) CDAY
      READ(10,2000,REC=3) TIME
      READ(10,2000,REC=6) UAVEL
      READ(10,2000,REC=7) UADIR
      READ(10,2000,REC=8) UATEMP
      READ(10,2000,REC=9) UAHT
      READ(10,2000,REC=10)LAPSE
      DO 10, I=1,5
       READ(10,2000,REC=(10+I))TPRES(I)
       READ(10,2000,REC=(15+I))TTEMP(I)
       READ(10,2000,REC=(20+I))TDIR(I)
       READ(10,2000,REC=(25+I))TVEL(I)
 10   CONTINUE
      OPEN(11,FILE='WINDS.DAT',STATUS='NEW')
C     **********************************
C     CALCULATE DATE AND TIME
C     **********************************
      IYEAR=NINT(YEAR-100*INT(YEAR/100))
      IYEAR=IYEAR*1000+CDAY
      ITIME=NINT(TIME)
      WRITE(11,100) IYEAR, ITIME
C     **********************************
C     LIST STATIONS
C     **********************************
      DATA
JT,XS,YS/1,2,3,4,5,539.6,521.5,547.8,539.5,557.1,3898.6,
     +3895.8,3927.5,3920.2,3901.7/
      DO 20,I=1,5
       WRITE(11,150) JT(I),XS(I),YS(I)
 20   CONTINUE
C     **********************************
C     ENTER TOWER DATA
C     **********************************
      DO 30, I=1,5
```

```
C        *********************************
C        CONVERT TTEMP TO CELCIUS AND TVEL TO M/S
C        *********************************
         TTEMP(I)=5./9.*(TTEMP(I)-32.)
         TVEL(I)=TVEL(I)*.514791
C        *********************************
         WRITE(11,200)TPRES(I),TTEMP(I),TDIR(I),TVEL(I)
 30     CONTINUE
C       *********************************
C       ASSIGN 850 WIND TO 2000 m
C       *********************************
        UAVEL=UAVEL*.514791
        WRITE(11,250)2,1026.,TDIR(2),TVEL(2),2000.,UADIR,UAVEL
C       ************ CALCULATE SFC - 850 LAPSE RATE **********
        DZ=1026.-UAHT
        DTDZ=(TTEMP(2)-UATEMP)/(DZ)
C       ******************** EXTRAPOLATE TO 2000 m ***********
        DH=2000.-UAHT
        T2=UATEMP+(DH*DTDZ)
        P2=850.-(DH*.1)
        OPEN(12,FILE='TEMPS.DAT',STATUS='NEW')
        WRITE(12,300)2,2
        WRITE(12,350)1026.,TTEMP(2),TPRES(2)
        WRITE(12,350)2000.,T2,P2
  11    FORMAT(A80)
  12    FORMAT(A1)
 100    FORMAT(I5,1X,I4)
 150    FORMAT(I1,1X,F6.1,1X,F7.1)
 200    FORMAT(F7.1,1X,F5.1,1X,F6.1,1X,F5.1)
 250    FORMAT(I1,2(/,F6.0,1X,F5.0,1X,F6.1))
 300    FORMAT(I1,1X,I1)
 350    FORMAT(F6.0,1X,F5.1,1X,F7.1)
 1000   FORMAT(I4)
 2000   FORMAT(F7.1)
        END
```

```
      PROGRAM INDXMAKR
C     *********************************
C     PROGRAM TO CALCULATE RAW LTI
C     *********************************
      REAL MACRO,WIND(61),ROUGH(61),MAXGRID
      REAL MROUGH,LAPSE,INDEX(61)
      INTEGER WRGRID(61)
      OPEN(10, FILE='WINDVEL.DAT',STATUS='OLD')
      OPEN(11, FILE='RUFFILE.DAT',STATUS='OLD')
      OPEN(12, FILE='WR.DAT',STATUS='NEW')
      OPEN(13, FILE='RAWINDEX.DAT',STATUS='NEW')
      OPEN (UNIT = 14,
     +        FILE = 'MAINDATA.DAT',
     +        ACCESS = 'DIRECT',
     +        STATUS = 'OLD',
     +        FORM = 'FORMATTED',
     +        RECL = 10)
C     *********************************
C     CALCULATE MACRO BTI
C     *********************************
      MROUGH = 5905.5/100.
      READ(14,2000,REC=4)APP
      READ(14,2000,REC=5)BYSWIND
      READ(14,2000,REC=10)LAPSE
      MACRO = MROUGH + BYSWIND + LAPSE + APP
C     *********************************
C     READ DATA FROM WIND FILE AND ROUGHNESS FILE, ADD
ROUGHNESS
C     TO WIND AND FIND MAX VALUE
C     *********************************
      MAXGRID = 0
      DO 10 J=1,61
       READ (10,*)(WIND(I), I=1,61)
       READ (11,*)(ROUGH(I), I=1,61)
       DO 31 I=1,61
           WRGRID(I) = NINT(WIND(I) + (ROUGH(I)/100))
           IF (WRGRID(I).GT.MAXGRID) MAXGRID = WRGRID(I)
  31   CONTINUE
       WRITE(12,1000)(WRGRID(I), I=1,61)
  10  CONTINUE
      CLOSE(12)
C     *********************************
C     CALCULATE TURBULENCE INDEX
C     *********************************
      OPEN(12, FILE='WR.DAT',STATUS='OLD')
      DO 40 J = 1,61
       READ(12,*)(WRGRID(I),I=1,61)
       DO 41, I=1,61
           INDEX(I) =((WRGRID(I)/MAXGRID) * MACRO)
  41   CONTINUE
       WRITE(13,4000)(INDEX(I),I=1,61)
```

```
 40  CONTINUE
     CLOSE(12,STATUS='DELETE')
1000 FORMAT(61(1X,I4))
4000 FORMAT(61(1X,F7.1))
2000 FORMAT(F7.1)
     END
```

```
      PROGRAM WINTERP
C     **********************************
C     THIS PROGRAM INTERPOLATES 2 KM WINDS TO FILL A 1 KM
GRID.
C     IT ALSO CALCULATES W COMPONENTS FOR THE 1 KM GRID.
C     **********************************
      REAL VEL(31,31),DIR(31,31),U(61,61),V(61,61)
      REAL S(61),D(61),DZDX(61),DZDY(61),W(61)
      DEG2RAD=1./57.295
      RAD2DEG=57.295
      OPEN(10,FILE='SPD.DAT',STATUS='OLD')
      OPEN(11,FILE='DIR.DAT',STATUS='OLD')
C     **********************************
C     READ 2 KM DATA
C     **********************************
      DO 10, J=31,1,-1
       READ(10,*)(VEL(I,J),I=1,31)
       READ(11,*)(DIR(I,J),I=1,31)
 10   CONTINUE
      CLOSE(10)
      CLOSE(11)
C     **********************************
C     CONVERT TO U AND V COMPONENTS
C     **********************************
      DO 20, J=1,61,2
       DO 21, I=1,61,2
            II=(I+1)/2
            JJ=(J+1)/2
            U(I,J)=-VEL(II,JJ)*SIN(DIR(II,JJ)*DEG2RAD)
            V(I,J)=-VEL(II,JJ)*COS(DIR(II,JJ)*DEG2RAD)
 21    CONTINUE
 20   CONTINUE
C     **********************************
C     INTERPOLATE COMPONENTS
C     **********************************
      DO 30, J=2,60,2
       DO 31, I=2,60,2
            U(I,J)=(U(I-1,J-1)+U(I+1,J-1)+U(I+1,J+1)+U(I-
1,J+1))/4.
            V(I,J)=(V(I-1,J-1)+V(I+1,J-1)+V(I+1,J+1)+V(I-
1,J+1))/4.
 31    CONTINUE
 30   CONTINUE
      DO 60, J=1,61,2
       DO 61, I=2,60,2
            IF(J.EQ.1)THEN
             U(I,J)=(U(I-1,J)+U(I+1,J)+U(I,J+1))/3.
             V(I,J)=(V(I-1,J)+V(I+1,J)+V(I,J+1))/3.
            ELSEIF(J.EQ.61)THEN
             U(I,J)=(U(I-1,J)+U(I+1,J)+U(I,J-1))/3.
             V(I,J)=(V(I-1,J)+V(I+1,J)+V(I,J-1))/3.
```

```
          ELSE
           U(I,J)=(U(I-1,J)+U(I+1,J)+U(I,J+1)+U(I,J-1))/4.
           V(I,J)=(V(I-1,J)+V(I+1,J)+V(I,J+1)+V(I,J-1))/4.
          ENDIF
 61      CONTINUE
 60     CONTINUE
        DO 70, J=2,60,2
         DO 71, I=1,61,2
          IF(I.EQ.1)THEN
           U(I,J)=(U(I+1,J)+U(I,J-1)+U(I,J+1))/3.
           V(I,J)=(V(I+1,J)+V(I,J-1)+V(I,J+1))/3.
          ELSEIF(I.EQ.61)THEN
           U(I,J)=(U(I-1,J)+U(I,J-1)+U(I,J+1))/3.
           V(I,J)=(V(I-1,J)+V(I,J-1)+V(I,J+1))/3.
          ELSE
           U(I,J)=(U(I-1,J)+U(I+1,J)+U(I,J+1)+U(I,J-1))/4.
           V(I,J)=(V(I-1,J)+V(I+1,J)+V(I,J+1)+V(I,J-1))/4.
          ENDIF
 71      CONTINUE
 70     CONTINUE
C       ***********************************
C       TRANSLATE BACK TO METEOROLOGICAL WINDS AND WRITE TO
FILES
C       ***********************************
        OPEN(15,FILE='WINDVEL.DAT',STATUS='NEW')
        OPEN(16,FILE='WINDDIR.DAT',STATUS='NEW')
        DO 50, J=61,1,-1
         DO 51, I=1,61
          IF(U(I,J).EQ.0.0.AND.V(I,J).EQ.0.0)THEN
           S(I)=0.0
           D(I)=0.0
          ELSE
           S(I)=SQRT(U(I,J)**2+V(I,J)**2)

D(I)=AMOD(540.+ATAN2(U(I,J),V(I,J))*RAD2DEG,360.)
           S(I)=S(I)*.194254
          ENDIF
 51      CONTINUE
         WRITE(15,1000)(S(I),I=1,61)
         WRITE(16,1000)(D(I),I=1,61)
 50     CONTINUE
        CLOSE(15)
        CLOSE(16)
C       ***********************************
C       CALCULATE W'S AND WRITE TO FILE
C       ***********************************
        OPEN(12,FILE='X.DAT',STATUS='OLD')
        OPEN(13,FILE='Y.DAT',STATUS='OLD')
        OPEN(14,FILE='W.DAT',STATUS='NEW')
        DO 40, J=61,1,-1
         READ(12,*)(DZDX(I),I=1,61)
```

```
      READ(13,*)(DZDY(I),I=1,61)
C     **********************************
C     TAKE DOT PRODUCT OF WIND AND TERRAIN, THEN CONVERT TO
KTS
C     **********************************
      DO 41, I=1,61
          W(I)=(U(I,J)*DZDX(I)+V(I,J)*DZDY(I))*.000194254
 41   CONTINUE
      WRITE(14,1000)(W(I), I=1,61)



40   CONTINUE
 1000 FORMAT(61(1X,F7.1))
     END
```

```
      PROGRAM INDXMOD
C     *********************************
C     PROGRAM TO MODIFY LTI BASED ON WAKE AND PIREPS
C     OUTPUT IS FOR CAT 1 AIRCRAFT
C     *********************************
      REAL YEAR, MYEAR, MTIME, TIME, YE, TI, INDEX(61,61)
      REAL Y(10), X(10), T(10), W(61), XX, YY, FACTOR
      INTEGER CDAY,CA,MCDAY,CHECK,ACCAT,IN(10),AC(10)
      INTEGER PIREP,TERRTYPE(61,61),AT,TME
      CHARACTER INTENS, ID
C     *********************************
C     LOAD INDEX ARRAY
C     *********************************
      OPEN(13,FILE='RAWINDEX.DAT',STATUS='OLD')
      DO 40, J=61,1,-1
       READ(13,*)(INDEX(I,J),I=1,61)
 40   CONTINUE
C     *********************************
C     ADD 20 FOR NEGATIVE W
C     *********************************
      OPEN(14,FILE='W.DAT',STATUS='OLD')
      MARKER=0
      DO 50, J=61,1,-1
       READ(14,4000)(W(I),I=1,61)
       DO 51, I=1,61
           IF(W(I).LT.-3.)THEN
            INDEX(I,J)=INDEX(I,J)+20.
            MARKER=MARKER+1
           ENDIF
 51    CONTINUE
 50   CONTINUE
      IF(MARKER.EQ.0)THEN
       WRITE(*,*)'No wake modifications.'
      ENDIF
C     *********************************
C     FIGURE SEARCH TIMES FOR PIREPS
C     *********************************
      OPEN (UNIT = 10,
     +        FILE = 'MAINDATA.DAT',
     +        ACCESS = 'DIRECT',
     +        STATUS = 'OLD',
     +        FORM = 'FORMATTED',
     +        RECL = 10)
      READ(10,2000,REC=1)YEAR
      READ(10,1000,REC=2)CDAY
      READ(10,1000,REC=3)TME
      TIME=FLOAT(TME)
      MTIME=TME-100
      MCDAY=CDAY
      MYEAR=YEAR
      IF (TME .LT. 100) THEN
```

```
          MTIME=2300+TME
          MCDAY=CDAY-1
          IF (CDAY.EQ.1) THEN
              YRES = AMOD((YEAR+1.),4.0)
              CRES = AMOD((YEAR+1.),100.0)
              MCDAY=365
              IF (YRES.EQ.0.0.AND.CRES.NE.0.0)MCDAY=366
              MYEAR=YEAR-1.
          ENDIF
         ENDIF
C        **********************************
C        LOOK FOR PIREPS
C        **********************************
         OPEN(UNIT=11,
     +          FILE='PIREP.DAT',
     +          ACCESS='DIRECT',
     +          STATUS='OLD',
     +          FORM='FORMATTED',
     +          RECL=50)
         ICT=0
         DO 10, I=1,999
          IND=I-1
          READ(11,101,REC=I,END=11)YE,CA,TI,XX,YY,ID,AT
          IF(YE.EQ.9999.)GO TO 10

IF((YE.LT.MYEAR).OR.(CA.LT.MCDAY).OR.(TI.LT.MTIME))THEN
              ICT=1+ICT
              GO TO 10
          ENDIF
          IND=IND-ICT
          IF((ID.EQ.'L').OR.(ID.EQ.'l'))IN(IND)=1
          IF((ID.EQ.'M').OR.(ID.EQ.'m'))IN(IND)=2
          IF((ID.EQ.'S').OR.(ID.EQ.'s'))IN(IND)=3
          IF((ID.EQ.'X').OR.(ID.EQ.'x'))IN(IND)=4
          IN(IND)=IN(IND)+(AT-1)
          T(IND)=TI
          X(IND)=XX
          Y(IND)=YY
 10      CONTINUE
 11      IF(IND.EQ.0) THEN
          WRITE(*,*)'There are no current PIREPS.'
          OPEN(15,FILE='NEWINDEX.DAT',STATUS='NEW')
          DO 70, J=61,1,-1
              WRITE(15,4000)(INDEX(I,J),I=1,61)
 70       CONTINUE
         GO TO 9999
         ELSE
          IND=IND-ICT-1
          IF((ID.EQ.'L').OR.(ID.EQ.'l'))IN(IND)=1
          IF((ID.EQ.'M').OR.(ID.EQ.'m'))IN(IND)=2
          IF((ID.EQ.'S').OR.(ID.EQ.'s'))IN(IND)=3
```

```
       IF((ID.EQ.'X').OR.(ID.EQ.'x'))IN(IND)=4
       IN(IND)=IN(IND)+(AT-1)
       T(IND)=TI
       X(IND)=XX
       Y(IND)=YY
      ENDIF
C     **********************************
C     READ TERRTYPE FILE
C     **********************************
      OPEN(12, FILE='TERRTYPE.DAT',STATUS='OLD')
      DO 18, I=1,61
       READ(12,*) (TERRTYPE(I,J), J=1,61)
 18   CONTINUE
C     **********************************
C     MODIFY LTI
C     **********************************
      DO 20, N=1,IND
C     **********************************
C     FIND NEAREST GRIDPOINT
C     **********************************
C     X
C     **********************************
       XMIN=506.1
       XX=X(N)-XMIN
       IX=NINT(XX)
C     **********************************
C     Y
C     **********************************
       YMIN=3887.0
       YY=Y(N)-YMIN
       IY=NINT(YY)
C     **********************************
C     CHECK FOR PIREP > INDEX
C     PIREP ASSIGNED MAXIMUM BTI VALUE FOR CATEGORY
C     **********************************
       PIREP=59.
       DO 30, L=1,IN(N)
           PIREP=FLOAT(L*10)+PIREP
 30    CONTINUE
       IF(INDEX(IX,IY).GE.PIREP)GO TO 20
       FACTOR=PIREP/INDEX(IX,IY)
       INDEX(IX,IY)=PIREP
C     **********************************
C     MODIFY INDEX AT LIKE TERRAIN
C     **********************************
       DO 21, I=1,61
           DO 22, J=1,61
            IF(I.EQ.IX.AND.J.EQ.IY)GO TO 22
            IF(TERRTYPE(I,J).EQ.TERRTYPE(IX,IY))THEN
                INDEX(I,J)=(INDEX(I,J)*FACTOR)
            ENDIF
```

```
22          CONTINUE
21      CONTINUE
20     CONTINUE
       OPEN(15,FILE='NEWINDEX.DAT',STATUS='NEW')
       DO 60, J=61,1,-1
        WRITE(15,4000)(INDEX(I,J),I=1,61)
60     CONTINUE
101    FORMAT(1X,F6.0,2X,I3,F6.0,2X,2(F11.1,2X),A1,2X,I1)
1000 FORMAT(I4)
2000 FORMAT(F7.1)
3000 FORMAT(61(I4))
4000 FORMAT(61(1X,F7.1))
9999 END
```

```
      PROGRAM LTIGRAPH
C MODIFIED TO 28x28 GRID AROUND 19 JULY 1988
C MODIFIED 28 JULY 1988
C SO THAT DATA FILES RESIDE IN DATA SUBDIRECTORY
C     MODIFIED FOR 61x61 GRID 3 FEB 1989 BY N. SMITH
C -----------------------------------------------------------
C     PROGRAM TO PLOT TURBULENCE INDEX
C -----------------------------------------------------------
$NOTRUNCATE
      dimension z(61,61),vert(61,61)
      REAL ZTERMI,ZTERMA, V_MIN, V_MAX
      INTEGER ITGRMI, JTGRMI, ITGRMA, JTGRMA, IVGRMI, JVGRMI
      INTEGER IVGRMA, JVGRMA, LEVEL
      COMMON ZTERMI,ITGRMI,JTGRMI,
     1         ZTERMA,ITGRMA,JTGRMA,
     2         V_MIN,IVGRMI,JVGRMI,
     3         V_MAX,IVGRMA,JVGRMA,
     4         TIGRMI,TJGRMI,TIGRMA,TJGRMA,
     5         VIGRMI,VJGRMI,VIGRMA,VJGRMA

C------------------------------------------------------------
C----------      DO THE TERRAIN CONTOURS     -----------------
       open(10,file='NTC1000.PLT')
C      READING THE TERRAIN FILE
       write(6,*)'Reading the terrain file...'
C      read(10,*) swx,swy,numx,numy,d
       do 100 J=61,1,-1
          read(10,*) (z(I,J),I=1,61)
  100 continue

C     Z IS THE FIRST FILE TO BE WRITTEN TO THE DATA FILE
      file=1
      call contour(z,file)
C------------------------------------------------------------
C-------    DO THE VERTICAL WIND FIELD CONTOURS     ---------
      write(6,90)
   90 format(//,1X,'Reading the turbulence file...')
      OPEN(22,FILE='NEWINDEX.DAT',STATUS='OLD')
      DO 1010 J=61,1,-1
      READ(22,4000) (VERT(I,J),I=1,61)
 4000 FORMAT(61(1X,F7.1))
 1010 CONTINUE
C     VERT IS THE SECOND FILE TO BE WRITTEN TO THE DATA FILE
      file=2
      call contour(Vert,file)
      CALL LABEL
      end
C------------------------------------------------------------
C------------------------------------------------------------
      SUBROUTINE CONTOUR(Z,file)
```

```
      REAL Z(61,61)
      DIMENSION XX(5),YY(5)
      DIMENSION X(61),Y(61)
      CHARACTER*15 FILENAME
      CHARACTER*10 ACCES
      CHARACTER*1 AELSTP
          COMMON ZTERMI,ITGRMI,JTGRMI,
     1         ZTERMA,ITGRMA,JTGRMA,
     2         V_MIN,IVGRMI,JVGRMI,
     3         V_MAX,IVGRMA,JVGRMA,
     4         TIGRMI,TJGRMI,TIGRMA,TJGRMA,
     5         VIGRMI,VJGRMI,VIGRMA,VJGRMA

       X9=1.0
       Y9=1.0
       DZ=-.021
       SCL=30./60.
       FILENAME='PLOT.DAT'
     IF(FILE .EQ. 1.) THEN
C--------SET UP FILE FOR TERRAIN DATA----------------------
      ACCES = 'SEQUENTIAL'
      NSTART=1
      NPOINTS=61
       ELSE
C------SET UP FILE FOR THE SECOND SET OF DATA, THE VERTICAL
WIND DATA-
C------POSITION FILE POINTER TO END OF FILE----------------
      ACCES = 'SEQUENTIAL'
   10      READ(LUOUT,'(1X)',END=20)
      GOTO 10
   20      NSTART=1
      NPOINTS=61
C--------BACKSPACE TO WRITE OVER THE END-OF-FILE MARKER-----
      BACKSPACE 8
       ENDIF
C     OPEN PLOT FILE TO BE WRITTEN
      LUOUT=8
      OPEN(UNIT=LUOUT,FILE=FILENAME,ACCESS=ACCES)
      IF(FILE .EQ. 1.) WRITE(LUOUT,45)'AF;IN;'
       NPOINTS=61
       DO 90 I=NSTART,NPOINTS
       X(I)=FLOAT(I-1)
       Y(I)=FLOAT(I-1)
   90  CONTINUE
  140  FORMAT(1X,61F5.0,/)
C      INITIALIZE PLOTTER
       WRITE(LUOUT,85) 'IN;'
       WRITE(LUOUT,55) 'IP1000,1000,7000,7000;'
       WRITE(LUOUT,65) 'SC0,30,0,30;'
   45  FORMAT(A6)
   55  FORMAT(A22)
```

```
   65  FORMAT(A12)
   75  FORMAT(A4)
   85  FORMAT(A3)
   95  FORMAT(A7)
       IF(file .eq. 1) CALL FRAME(LUOUT)
C-----------------------------------------------------------------
       WRITE(LUOUT,85)'SP6;'
C      if not the first file, choose pen 2
       IF(file .ne. 1.) WRITE(LUOUT,75) 'SP2;'
       ZMIN=9999999
       ZMAX=-99999
      IF(FILE .EQ. 1) THEN
     DO 150 I=1,61
      DO 150 J=1,61
       ZMIN=AMIN1(ZMIN,Z(I,J))
       ZMAX=AMAX1(ZMAX,Z(I,J))
  150     CONTINUE


      DO 160 I=1,61
     DO 160 J=1,61
      IF(Z(I,J) .EQ. ZMIN) THEN
       IMIN=I
       JMIN=J
      ENDIF
      IF(Z(I,J) .EQ. ZMAX) THEN
       IMAX=I
       JMAX=J
      ENDIF
 160  CONTINUE
       TIGRMI = FLOAT(IMIN-1)+506.1
       TJGRMI = FLOAT(JMIN-1)+3887.0
       WRITE (6,280)ZMIN,TIGRMI,TJGRMI
       ZTERMI = ZMIN
       ITGRMI = IMIN-1
       JTGRMI = JMIN-1
       TIGRMA = FLOAT(IMAX-1)+506.1
       TJGRMA = FLOAT(JMAX-1)+3887.0
       WRITE (6,285)ZMAX,TIGRMA,TJGRMA
       ZTERMA = ZMAX
       ITGRMA = IMAX-1
       JTGRMA = JMAX-1
      ENDIF
      IF(FILE .EQ. 2) THEN
       DO 151 I=1,61
     DO 151 J=1,61
       ZMIN=AMIN1(ZMIN,Z(I,J))
       ZMAX=AMAX1(ZMAX,Z(I,J))
  151  CONTINUE
       DO 161 I=1,61
     DO 161 J=1,61
```

```
      IF(Z(I,J) .EQ. ZMIN) THEN
       IMIN=I
       JMIN=J
      ENDIF
      IF(Z(I,J) .EQ. ZMAX) THEN
       IMAX=I
       JMAX=J
      ENDIF
 161   CONTINUE
       VIGRMI = FLOAT(IMIN-1)+506.1
       VJGRMI = FLOAT(JMIN-1)+3887.0
       WRITE (6,290)ZMIN,VIGRMI,VJGRMI
       V_MIN = ZMIN
       IVGRMI = IMIN-1
       JVGRMI = JMIN-1
       VIGRMA = FLOAT(IMAX-1)+506.1
       VJGRMA = FLOAT(JMAX-1)+3887.0
       WRITE (6,295)ZMAX,VIGRMA,VJGRMA
       V_MAX = ZMAX
       IVGRMA = IMAX-1
       JVGRMA = JMAX-1
       ENDIF
  280  FORMAT(/,' Min ',f10.4,' m at (',F5.1,',',F6.1,')')
  285  FORMAT(' Max ',f10.4,' m at (',F5.1,',',F6.1,')')
  290  FORMAT(/,' Min ',f10.4,' at (',F5.1,',',F6.1,')')
  295  FORMAT(' Max ',f10.4,' at (',F5.1,',',F6.1,')')
C      Default value for elstp to generate 10 contour lines
C      ELSTP=(ZMAX-ZMIN)/10.
       WRITE(6,175) ELSTP
  175  FORMAT(A1)
       IF(FILE .EQ. 1) THEN
     ELSTP=200
C    WRITE(6,*) '   You may choose: '
C    WRITE(6,*) '                        a  100 meters'
C    WRITE(6,*) '                        b  200 meters'
C    WRITE(6,*) '                        c  500 meters'
C    WRITE(6,*) '                        d 1000 meters'
C    WRITE(6,*) '                        e no contours'
C    WRITE(6,*) '   for contour interval.'
C    WRITE(6,*)
C    WRITE(6,*) ' Input a,b,c,d, or e:  '
C    READ(5,175) AELSTP
C    IF(AELSTP .EQ. 'A' .OR. AELSTP .EQ. 'a') ELSTP=100.
C    IF(AELSTP .EQ. 'B' .OR. AELSTP .EQ. 'b') ELSTP=200.
C    IF(AELSTP .EQ. 'C' .OR. AELSTP .EQ. 'c') ELSTP=500.
C    IF(AELSTP .EQ. 'D' .OR. AELSTP .EQ. 'd') ELSTP=1000.
C    IF(AELSTP .EQ. 'E' .OR. AELSTP .EQ. 'e') ELSTP=900000.
       ELSE
       ELSTP=10.
     IF(MAX(ABS(ZMIN),ABS(ZMAX)) .GE.120.0) THEN
```

```
WRITE(6,*)'=============================================='
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,178)
  178      FORMAT(' ----CAUTION: SOME EXTREME TURBULENCE----
')
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*)

WRITE(6,*)'=============================================='
      WRITE(6,*)
      PAUSE' Press Enter to continue...'
      ENDIF
      IF(ZMAX-ZMIN .LT. 1.) THEN
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)

WRITE(6,*)'============================================='
       WRITE(6,*)
       WRITE(6,177)
  177      FORMAT(' Range of turbulence index is less
than',
     &          ' 1 .')
       WRITE(6,*)(' The turbulence index is uniform.')
       WRITE(6,*)

WRITE(6,*)'============================================='
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)
       PAUSE' Press Enter to continue...'
       CLOSE(UNIT=LUOUT,STATUS='DELETE')
       GOTO 1020
      ENDIF
      WRITE(6,176)ELSTP
 176  FORMAT(' Contour level for turbulence index is ',F5.2,
     &        '.')
     ENDIF
c    IF(ELSTP .LT. (ZMAX-ZMIN)/30.) ELSTP=(ZMAX-ZMIN)/10.
     MI=AINT(ZMIN/ELSTP)
     MA=AINT(ZMAX/ELSTP)
     WRITE(6,*) 'Generating Plot file from data files... '
```

```
      DO 1010 K=MI,MA
        IF(FILE.EQ.2) THEN
 IF(K.EQ.6.OR.K.EQ.7.OR.K.EQ.9.OR.K.EQ.10.OR.K.EQ.12)THEN
             GO TO 444
            ELSE
             GO TO 1010
            ENDIF
  444   ENDIF
         F=FLOAT(K)*ELSTP+DZ
         IF(K.eq.10) THEN
          IF(file.EQ.2)WRITE(LUOUT,75)'SP4;'
         ENDIF
         IF(K.eq.7) THEN
          IF(file.EQ.2)WRITE(LUOUT,75)'SP3;'
         ENDIF
         IF(K.ge.12) THEN
          IF(file.EQ.2)WRITE(LUOUT,75)'SP5;'
         ENDIF
         IF(K .le. MI.or.k.lt.7) THEN
          IF(file .EQ. 2)WRITE(LUOUT,75)'SP2;'
          IF(file .EQ. 1)WRITE(LUOUT,75)'SP6;'
         ENDIF
         IF(K.eq.9) THEN
          IF(file .EQ. 2)WRITE(LUOUT,75)'SP8;'
         ENDIF
         WRITE(LUOUT,85) 'PU;'
      DO 1000 I=1,60
      DO 1000 J=1,60
         F0=Z(I,J)-F
         F1=Z(I+1,J)-F
         F2=Z(I,J+1)-F
         F3=Z(I+1,J+1)-F
         IC=1
         G=F0*F1
         IF(G.LE.0.0) THEN
           XX(IC)=((X(I)*F1-(X(I)+X9)*F0)/(F1-F0))*SCL
           YY(IC)=(Y(J))*SCL
           IC=IC+1
         END IF
         G=F2*F0
         IF(G.LE.0.0) THEN
           XX(IC)=(X(I))*SCL
           YY(IC)=((Y(J)*F2-(Y(J)+Y9)*F0)/(F2-F0))*SCL
           IC=IC+1
         END IF
         G=F3*F1
         IF(G.LE.0.0) THEN
           XX(IC)=(X(I)+X9)*SCL
           YY(IC)=((Y(J)*F3-(Y(J)+Y9)*F1)/(F3-F1))*SCL
           IC=IC+1
```

```
      END IF
      G=F3*F2
      IF(G.LE.0.0) THEN
        XX(IC)=((X(I)*F3-(X(I)+X9)*F2)/(F3-F2))*SCL
        YY(IC)=(Y(J)+Y9)*SCL
        IC=IC+1
      END IF
      IF(IC.EQ.1) GO TO 1000
      IF(IC.EQ.5) GO TO 2000
      CALL FORMT(XX(1),YY(1),LUOUT)
      WRITE(LUOUT,85) 'PD;'
      CALL FORMT(XX(2),YY(2),LUOUT)
      WRITE(LUOUT,85) 'PU;'
      GO TO 1000
2000       IF(FO.LE.0.AND.F3.LE.0.0) THEN
   DO 2001 M=1,2
        N=M+2
   CALL FORMT(XX(M),YY(M),LUOUT)
   WRITE(LUOUT,85) 'PD;'
   CALL FORMT(XX(N),YY(N),LUOUT)
   WRITE(LUOUT,85) 'PU;'
2001    CONTINUE
   ELSE
   DO 2002 M=1,3,2
        N=M+1
   CALL FORMT(XX(M),YY(M),LUOUT)
   WRITE(LUOUT,85) 'PD;'
   CALL FORMT(XX(N),YY(N),LUOUT)
   WRITE(LUOUT,85) 'PU;'
2002    CONTINUE
   ENDIF
1000    CONTINUE
   IF(K .EQ. 0 .OR. K .LE. MI .OR. K .EQ. MA) THEN
   IF(file .EQ. 1) WRITE(LUOUT,75)'SP6;'
   IF(file .EQ. 2) WRITE(LUOUT,75)'SP2;'
   ENDIF
1010    CONTINUE
   IF(FILE .EQ. 2) WRITE(LUOUT,85)'AF;'
1020    CONTINUE
   RETURN
   END
C------------------------------------------------------------
      SUBROUTINE FRAME(LUOUT)
C     DRAW THE THE FRAME
      WRITE(LUOUT,5)
'SP1;PU;PA0,0;PD;PA0,30;PA30,30;PA30,0;PA0,0;PU;'
    5 FORMAT(A47)
      DO 100 I=1,31
   IF(I .LT. 11) WRITE(LUOUT,10)I-1,'0',I-1,'0.5'
 100    IF(I .GE. 11) WRITE(LUOUT,20)I-1,'0',I-1,'0.5'
```

```
   10  FORMAT('PA',I1,',',A1,';',
'PD',';','PA',I1,',',A3,';','PU',';')
   20  FORMAT('PA',I2,',',A1,';',
'PD',';','PA',I2,',',A3,';','PU',';')
       DO 200 I=1,31
     IF(I .LT. 11) WRITE(LUOUT,30)'30',I-1,'29.5',I-1
  200       IF(I .GE. 11) WRITE(LUOUT,40)'30',I-1,'29.5',I-1
   30  FORMAT('PA',A2,',',I1,';',
'PD',';','PA',A4,',',I1,';','PU',';')
   40  FORMAT('PA',A2,',',I2,';',
'PD',';','PA',A4,',',I2,';','PU',';')
       DO 300 I=31,1,-1
     IF(I .LT. 11) WRITE(LUOUT,50)I-1,'30',I-1,'29.5'
  300       IF(I .GE. 11) WRITE(LUOUT,60)I-1,'30',I-1,'29.5'
   50  FORMAT('PA',I1,',',A2,';',
'PD',';','PA',I1,',',A4,';','PU',';')
   60  FORMAT('PA',I2,',',A2,';',
'PD',';','PA',I2,',',A4,';','PU',';')
       DO 400 I=31,1,-1
     IF(I .LT. 11) WRITE(LUOUT,70)'0',I-1,'0.5',I-1
  400       IF(I .GE. 11) WRITE(LUOUT,80)'0',I-1,'0.5',I-1
   70  FORMAT('PA',A1,',',I1,';',
'PD',';','PA',A3,',',I1,';','PU',';')
   80  FORMAT('PA',A1,',',I2,';',
'PD',';','PA',A3,',',I2,';','PU',';')
C---------DONE DRAWING FRAME--------------
       CALL MAP(LUOUT)
       RETURN
       END
C=============================================================
C
       SUBROUTINE FORMT(X,Y,LUOUT)
     IF (X .LT. 9.995 .AND. Y .LT. 9.995) WRITE(LUOUT,1100)
X,Y
     IF (X .LT. 9.995 .AND. Y .GE. 9.995) WRITE(LUOUT,1101)
X,Y
     IF (X .GE. 9.995 .AND. Y .LT. 9.995) WRITE(LUOUT,1110)
X,Y
     IF (X .GE. 9.995 .AND. Y .GE. 9.995) WRITE(LUOUT,1111)
X,Y
 1100       FORMAT('PA',F4.2,',',F4.2,';')
 1101       FORMAT('PA',F4.2,',',F5.2,';')
 1110       FORMAT('PA',F5.2,',',F4.2,';')
 1111       FORMAT('PA',F5.2,',',F5.2,';')
       RETURN
       END
C=============================================================
C
       SUBROUTINE LABEL
     COMMON ZTERMI,ITGRMI,JTGRMI,
     1         ZTERMA,ITGRMA,JTGRMA,
```

```
     2          V_MIN,IVGRMI,JVGRMI,
     3          V_MAX,IVGRMA,JVGRMA,
     4          TIGRMI,TJGRMI,TIGRMA,TJGRMA,
     5          VIGRMI,VJGRMI,VIGRMA,VJGRMA
      CHARACTER*80   STRING
      CHARACTER*15 FILENAME
      CHARACTER*10 LAB
      FILENAME='PLOT.DAT'
      LUOUT=8
C          DRAW BOX
      CALL BOX(LUOUT,1,31.,0.,45.,0.,45.,30.1,31.,30.1)
      CALL BOX(LUOUT,1,31.,28.,45.,28.,45.,30.1,31.,30.1)
C     WRITE(LUOUT,*)'SP8;PU;PA31,0;PD;PA47,0;PA47,30;PA31,30;
PA31,0;'

C-------ASL LABEL-----------------------
      WRITE(LUOUT,*) 'SP5;'
      WRITE(STRING,99)
      CALL LBCOMMAND(LUOUT,31.5,29.3,STRING)

C-------FIRST LABEL---------------------
      WRITE(LUOUT,*) 'SP4;'
      WRITE(STRING,100)
      CALL LBCOMMAND(LUOUT,31.5,27.,STRING)

      WRITE(STRING,101) ZTERMA,' m '
      CALL LBCOMMAND(LUOUT,31.5,26.,STRING)

      WRITE(STRING,102) TIGRMA,TJGRMA
      CALL LBCOMMAND(LUOUT,31.5,25.,STRING)

C-------SECOND LABEL--------------------
      WRITE(STRING,103)
      CALL LBCOMMAND(LUOUT,31.5,23.,STRING)

      WRITE(STRING,101) ZTERMI,' m '
      CALL LBCOMMAND(LUOUT,31.5,22.,STRING)

      WRITE(STRING,102) TIGRMI,TJGRMI
      CALL LBCOMMAND(LUOUT,31.5,21.,STRING)

C-------THIRD LABEL---------------------
      WRITE(STRING,104)
      CALL LBCOMMAND(LUOUT,31.5,19.,STRING)
      WRITE(STRING,105) V_MAX,' '
      CALL LBCOMMAND(LUOUT,31.5,18.,STRING)

      WRITE(STRING,102) VIGRMA,VJGRMA
      CALL LBCOMMAND(LUOUT,31.5,17.,STRING)

C-------FOURTH LABEL-------------------
```

```
      WRITE(STRING,106)
      CALL LBCOMMAND(LUOUT,31.5,15.,STRING)

      WRITE(STRING,105) V_MIN,' '
      CALL LBCOMMAND(LUOUT,31.5,14.,STRING)

      WRITE(STRING,102) VIGRMI,VJGRMI
      CALL LBCOMMAND(LUOUT,31.5,13.,STRING)

C-------FIFTH-NINTH LABELS-------------
      WRITE(LUOUT,*) 'SP6;'
      WRITE(STRING,107)
      CALL LBCOMMAND(LUOUT,31.5,10.5,STRING)

      WRITE(LUOUT,*) 'SP5;'
      WRITE(STRING,108)
      CALL LBCOMMAND(LUOUT,31.5,9.,STRING)

      WRITE(LUOUT,*) 'SP4;'
      WRITE(STRING,109)
      CALL LBCOMMAND(LUOUT,31.5,7.5,STRING)

      WRITE(LUOUT,*) 'SP8;'
      WRITE(STRING,110)
      CALL LBCOMMAND(LUOUT,31.5,6.,STRING)


      WRITE(LUOUT,*) 'SP3;'
      WRITE(STRING,111)
      CALL LBCOMMAND(LUOUT,31.5,4.5,STRING)

      WRITE(LUOUT,*) 'SP2;'
      WRITE(STRING,112)
      CALL LBCOMMAND(LUOUT,31.5,3.,STRING)

C     REWIND(22)
C     READ(22,*) LEVEL
C     WRITE(LUOUT,*) 'SP3;'
C     WRITE(STRING,113) ' LEVEL',LEVEL
C     CALL LBCOMMAND(LUOUT,31.5,1.3,STRING)

   99      FORMAT('** TURBULENCE INDEX **')
  100      FORMAT('Terrain Maximum of')
  101      FORMAT(F7.1,A3)
  102      FORMAT('at (',F5.1,',',F7.1,')')
  103      FORMAT('Terrain Minimum of')
  104      FORMAT('Turb. index maximum of')
  105      FORMAT(F7.2,A5)
  106      FORMAT('Turb. index minimum of')
  107      FORMAT('Terrain Contours')
  108      FORMAT('Extreme Turb.   > 120')
```

```
109     FORMAT('Severe Turb.  100-119')
110     FORMAT('Mod.-Sev. Turb. 90-99')
111     FORMAT('Mod. Turb.      70-89')
112     FORMAT('Light Turb.     60-69')
113     FORMAT(A17,I3)
      WRITE(LUOUT,*) 'SP0;AF;'
      RETURN
      END
C============================================================
C
      SUBROUTINE     LBCOMMAND(LUOUT,X,Y,STRING)
C------------------------------------------------------------
      INTEGER   LUOUT
      REAL*4         X,Y
      CHARACTER*80   STRING

      CHARACTER*1    TERMINATOR
C------------------------------------------------------------
      TERMINATOR=CHAR(3)

      WRITE(LUOUT,*) 'PU;PA',X,',',Y,';',
      2              'LB',STRING(1:22),TERMINATOR,';PU;'
      RETURN
      END
C============================================================
C
      SUBROUTINE     BOX(LUOUT,PEN,X1,Y1,X2,Y2,X3,Y3,X4,Y4)
C     DRAW BOX
C------------------------------------------------------------
      INTEGER   LUOUT,PEN
      REAL*4         X1,Y1,X2,Y2,X3,Y3,X4,Y4
C------------------------------------------------------------
      WRITE(LUOUT,*) 'SP',PEN,';PU;PA',X1,',',Y1,';PD;',
      2                'PA',X2,',',Y2,',',X3,',',Y3,',',
      3                X4,',',Y4,',',X1,',',Y1,';PU;'
      RETURN
      END
C============================================================
C
       SUBROUTINE MAP(LUOUT)
C      DRAWS MAP OF NTC
C------------------------------------------------------------
       INTEGER LUOUT
       WRITE(LUOUT,*) 'SP1;PU;'
       WRITE(LUOUT,*)'PA6.05,.7;PD;'
       WRITE(LUOUT,*)'PA6.05,2.35;'
       WRITE(LUOUT,*)'PA5.05,2.35;'
       WRITE(LUOUT,*)'PA5.05,8.9;'
       WRITE(LUOUT,*)'PA3.6,8.9;'
       WRITE(LUOUT,*)'PA3.6,10.55;'
       WRITE(LUOUT,*)'PA.3,10.55;'
```

```
WRITE(LUOUT,*)'PA.3,27.7;'
WRITE(LUOUT,*)'PA19.85,27.7;'
WRITE(LUOUT,*)'PA19.85,24.5;'
WRITE(LUOUT,*)'PA24.7,24.5;'
WRITE(LUOUT,*)'PA24.7,23.75;'
WRITE(LUOUT,*)'PA27.15,23.75;'
WRITE(LUOUT,*)'PA27.15,21.3;'
WRITE(LUOUT,*)'PA27.95,21.3;'
WRITE(LUOUT,*)'PA27.95,8.0;'
WRITE(LUOUT,*)'PA26.25,8.0;'
WRITE(LUOUT,*)'PA26.25,7.2;'
WRITE(LUOUT,*)'PA25.4,7.2;'
WRITE(LUOUT,*)'PA25.4,6.35;'
WRITE(LUOUT,*)'PA24.6,6.35;'
WRITE(LUOUT,*)'PA24.6,5.55;'
WRITE(LUOUT,*)'PA23.75,5.55;'
WRITE(LUOUT,*)'PA23.75,3.9;'
WRITE(LUOUT,*)'PA22.9,3.9;'
WRITE(LUOUT,*)'PA22.9,3.15;'
WRITE(LUOUT,*)'PA22.15,3.15;'
WRITE(LUOUT,*)'PA22.15,2.35;'
WRITE(LUOUT,*)'PA21.35,2.35;'
WRITE(LUOUT,*)'PA21.35,.7;'
WRITE(LUOUT,*)'PA20.55,.7;'
WRITE(LUOUT,*)'PA20.55,-.1;'
WRITE(LUOUT,*)'PA10.05,-.1;'
WRITE(LUOUT,*)'PA10.05,.7;'
WRITE(LUOUT,*)'PA8.4,.7;'
WRITE(LUOUT,*)'PA8.4,1.6;'
WRITE(LUOUT,*)'PA6.8,1.6;'
WRITE(LUOUT,*)'PA6.8,.7;'
WRITE(LUOUT,*)'PA6.05,.7;PU;'
RETURN
END
```

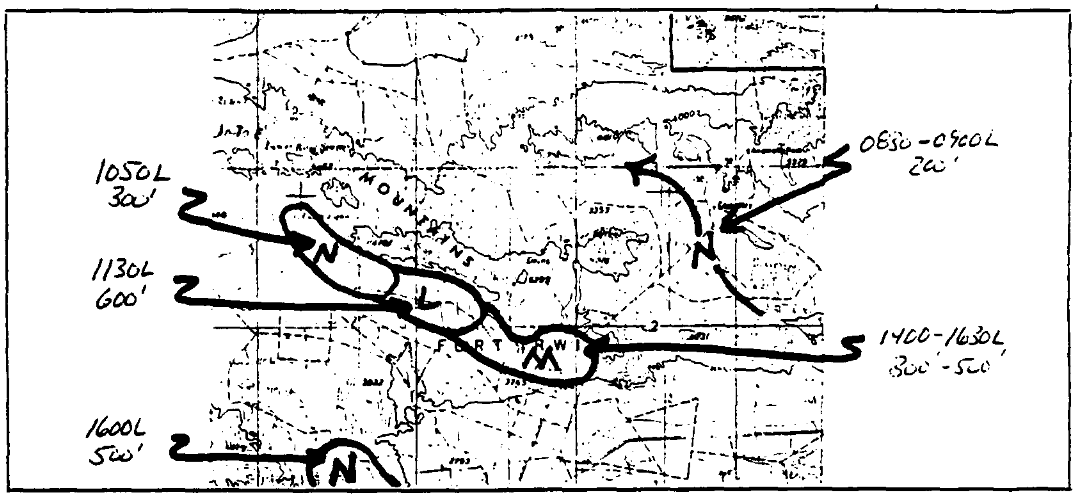
APPENDIX III: PIREP Questionnaire.

A questionnaire such as this was completed by permanent-party pilots after each mission flown at NTC during two 2-week training periods between 27 February and 12 May, 1988. On the reverse side of the questionnaire was a contour map of the Ft Irwin area. Data from those areas annotated by the pilots were consolidated and used to modify the LTI.

DATE________________

POST-FLIGHT TURBULENCE SURVEY

EXAMPLE



INSTRUCTIONS

ON THE MAP ON THE REVERSE, REPORT THE FOLLOWING: (NAME OR AIRCRAFT ID NOT REQUIRED - BE AS SPECIFIC AS POSSIBLE)

1. LOCATION.
2. TIME (LOCAL).
3. ALTITUDE ABOVE GROUND LEVEL (AGL).
4. TURBULENCE INTENSITY. USE STANDARD REPORTING CATEGORIES: None(N), Light(L), Moderate(M), Severe(S), eXtreme(X) PLEASE INCLUDE NEGATIVE (N) REPORTS.
5. SEE EXAMPLE ABOVE.

APPENDIX IV: LTI Inputs and Displays

Tables list measured surface parameters at BYS and five sensor locations throughout NTC, and interpolated 850 mb parameters. Figures are hard-copy reproductions of video displays generated by the LTI program. On the figures, isopleths of threshold LTI values for turbulence categories (Category I aircraft) are overlaid on 200 m terrain contours and an outline of Ft Irwin. Horizontal "tic" marks are drawn at 2 km intervals.

Case		Site	Press (mb)	Temp (°F)	Dir	Speed (kts)
29 Feb 1200Z						
		BYS	899.9	49	267	11
APP (mb)	-0.5	Tower 1	921.5	52	285	11
850 Height (m)	1510	Tower 2	899.9	49	267	11
850 Temp (°C)	6	Tower 3	894.4	49	299	4
850 Wind Dir.	160	Tower 4	882.6	48	246	9
850 Wind Spd (kts)	15	Tower 5	937.7	55	100	2
01 Mar 0000Z						
		BYS	898.4	56	236	12
APP (mb)	-1.0	Tower 1	919.5	61	236	19
850 Height (m)	1495	Tower 2	898.4	56	236	12
850 Temp (°C)	10	Tower 3	892.2	58	202	16
850 Wind Dir.	210	Tower 4	881.0	54	220	13
850 Wind Spd (kts)	20	Tower 5	934.6	64	227	28
01 Mar 1200Z						
		BYS	897.9	44	238	6
APP (mb)	-1.2	Tower 1	919.2	48	242	12
850 Height (m)	1488	Tower 2	897.9	44	238	6
850 Temp (°C)	5	Tower 3	891.4	47	256	9
850 Wind Dir.	245	Tower 4	879.9	44	227	10
850 Wind Spd (kts)	15	Tower 5	935.7	50	206	8
02 Mar 0000Z						
		BYS	893.9	54	250	17
APP (mb)	-2.4	Tower 1	915.2	59	236	19
850 Height (m)	1443	Tower 2	893.9	54	250	17
850 Temp (°C)	8	Tower 3	888.2	54	238	10
850 Wind Dir.	212	Tower 4	876.5	52	215	13
850 Wind Spd (kts)	16	Tower 5	931.0	61	227	21
05 Mar 1200Z						
		BYS	902.5	53	258	6
APP (mb)	-0.4	Tower 1	923.9	57	279	3
850 Height (m)	1527	Tower 2	902.5	53	258	6
850 Temp (°C)	12	Tower 3	896.7	51	345	2
850 Wind Dir.	30	Tower 4	885.1	50	43	3
850 Wind Spd (kts)	3	Tower 5	939.8	56	150	4
06 Mar 0000Z						
		BYS	902.4	70	153	4
APP (mb)	-1.8	Tower 1	923.3	74	205	8
850 Height (m)	1533	Tower 2	902.4	70	153	4
850 Temp (°C)	13	Tower 3	896.5	68	171	7
850 Wind Dir.	340	Tower 4	885.2	66	173	6
850 Wind Spd (kts)	5	Tower 5	939.0	75	215	4

06 Mar 1200Z

		BYS	900.7	52	261	9
APP (mb)	-1.3	Tower 1	921.8	56	254	10
850 Height (m)	1518	Tower 2	900.7	52	261	9
850 Temp (°C)	12	Tower 3	894.7	54	124	8
850 Wind Dir.	250	Tower 4	883.2	52	199	4
850 Wind Spd (kts)	5	Tower 5	937.9	57	198	7

07 Mar 0000Z

		BYS	896.9	65	236	11
APP (mb)	-1.3	Tower 1	917.8	69	234	13
850 Height (m)	1492	Tower 2	896.9	65	236	11
850 Temp (°C)	14	Tower 3	890.8	66	288	6
850 Wind Dir.	280	Tower 4	879.8	64	241	6
850 Wind Spd (kts)	10	Tower 5	933.3	71	224	18

22 Apr 1200Z

		BYS	890.6	44	248	8
APP (mb)	0.6	Tower 1	911.6	47	239	17
850 Height (m)	1433	Tower 2	890.6	44	248	8
850 Temp (°C)	4	Tower 3	884.6	43	130	6
850 Wind Dir.	280	Tower 4	872.6	42	223	7
850 Wind Spd (kts)	10	Tower 5	927.7	49	215	20

23 Apr 0000Z

		BYS	892.9	56	227	17
APP (mb)	-0.2	Tower 1	913.8	60	227	27
850 Height (m)	1461	Tower 2	892.9	56	227	17
850 Temp (°C)	6	Tower 3	886.7	57	214	14
850 Wind Dir.	245	Tower 4	875.0	54	210	18
850 Wind Spd (kts)	10	Tower 5	929.5	63	219	24

25 Apr 1200Z

		BYS	899.7	50	266	9
APP (mb)	-0.4	Tower 1	920.9	53	231	16
850 Height (m)	1509	Tower 2	899.7	50	266	9
850 Temp (°C)	12	Tower 3	893.5	52	158	8
850 Wind Dir.	280	Tower 4	882.3	48	32	2
850 Wind Spd (kts)	10	Tower 5	937.0	55	191	8

26 Apr 0000Z

		BYS	898.4	73	101	5
APP (mb)	-1.5	Tower 1	919.3	74	57	5
850 Height (m)	1515	Tower 2	898.4	73	101	5
850 Temp (°C)	16	Tower 3	892.5	71	285	4
850 Wind Dir.	290	Tower 4	881.4	70	13	6
850 Wind Spd (kts)	3	Tower 5	934.8	78	54	2

26 Apr 1200Z

		BYS	897.7	64	328	2
APP (mb)	-0.7	Tower 1	918.7	64	55	3
850 Height (m)	1489	Tower 2	897.7	64	328	2
850 Temp (°C)	15	Tower 3	892.0	58	67	4
850 Wind Dir.	180	Tower 4	880.7	56	40	2
850 Wind Spd (kts)	2	Tower 5	934.2	62	105	3

28 Apr 1200Z

		BYS	892.3	53	275	22
APP (mb)	-0.7	Tower 1	914.2	59	248	14
850 Height (m)	1465	Tower 2	892.3	53	275	22
850 Temp (°C)	10	Tower 3	887.5	57	293	5
850 Wind Dir.	220	Tower 4	875.9	56	251	11
850 Wind Spd (kts)	10	Tower 5	929.6	62	208	18

10 May 1200Z

		BYS	903.5	67	20	4
APP (mb)	0.1	Tower 1	924.5	68	236	2
850 Height (m)	1549	Tower 2	903.5	67	20	4
850 Temp (°C)	18	Tower 3	897.8	63	270	3
850 Wind Dir.	40	Tower 4	886.5	60	10	3
850 Wind Spd (kts)	10	Tower 5	939.9	69	162	4

11 May 0000Z

		BYS	903.4	86	103	3
APP (mb)	-1.8	Tower 1	923.9	90	209	3
850 Height (m)	1559	Tower 2	903.4	86	103	3
850 Temp (°C)	22	Tower 3	897.3	84	354	6
850 Wind Dir.	25	Tower 4	886.7	83	20	5
850 Wind Spd (kts)	10	Tower 5	938.9	91	348	5

11 May 1200Z

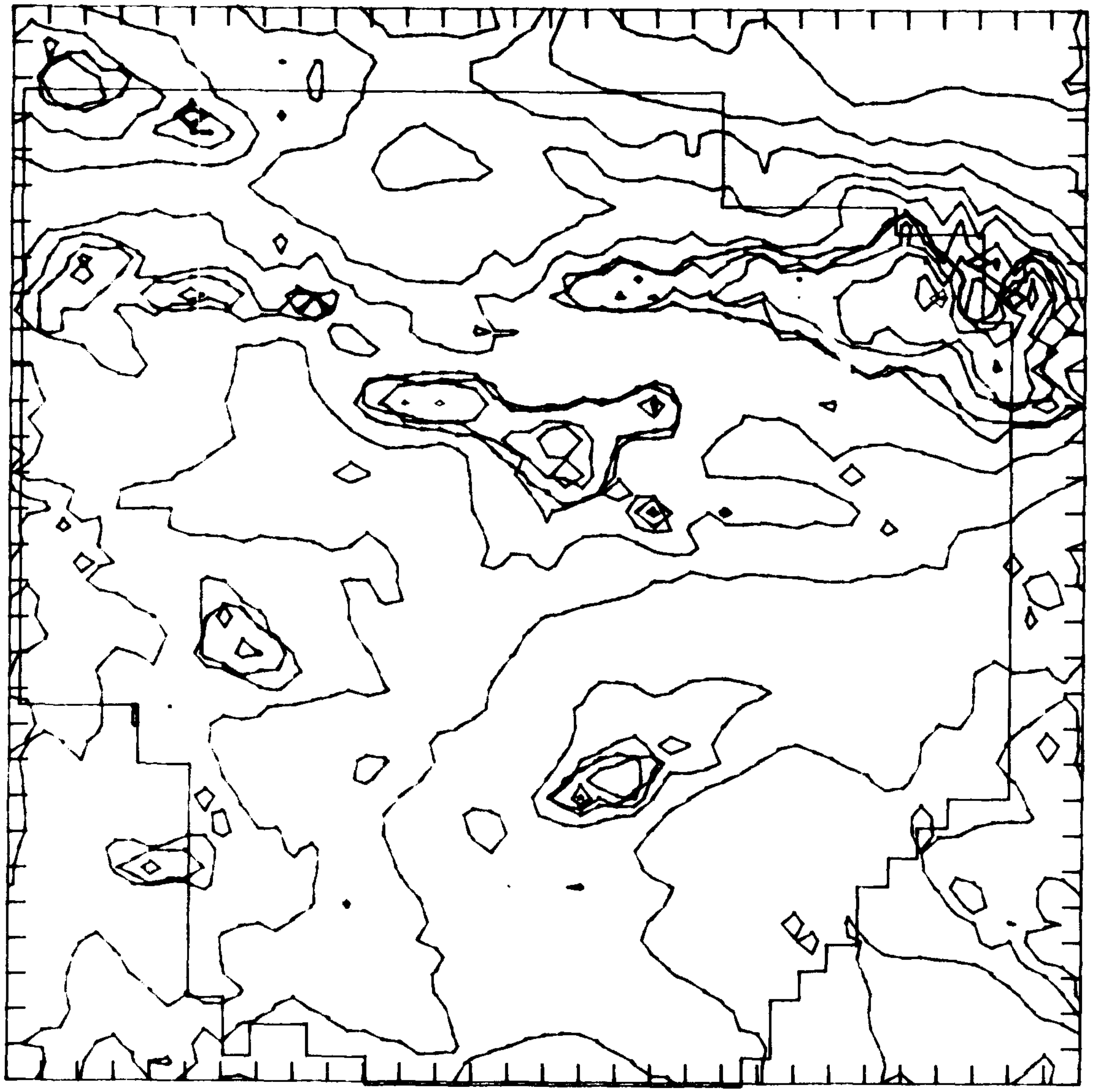
		BYS	902.9	74	343	9
APP (mb)	-0.2	Tower 1	923.7	76	61	6
850 Height (m)	1555	Tower 2	902.9	74	343	9
850 Temp (°C)	20	Tower 3	897.4	70	44	5
850 Wind Dir.	350	Tower 4	886.2	72	320	10
850 Wind Spd (kts)	2	Tower 5	939.1	72	74	4

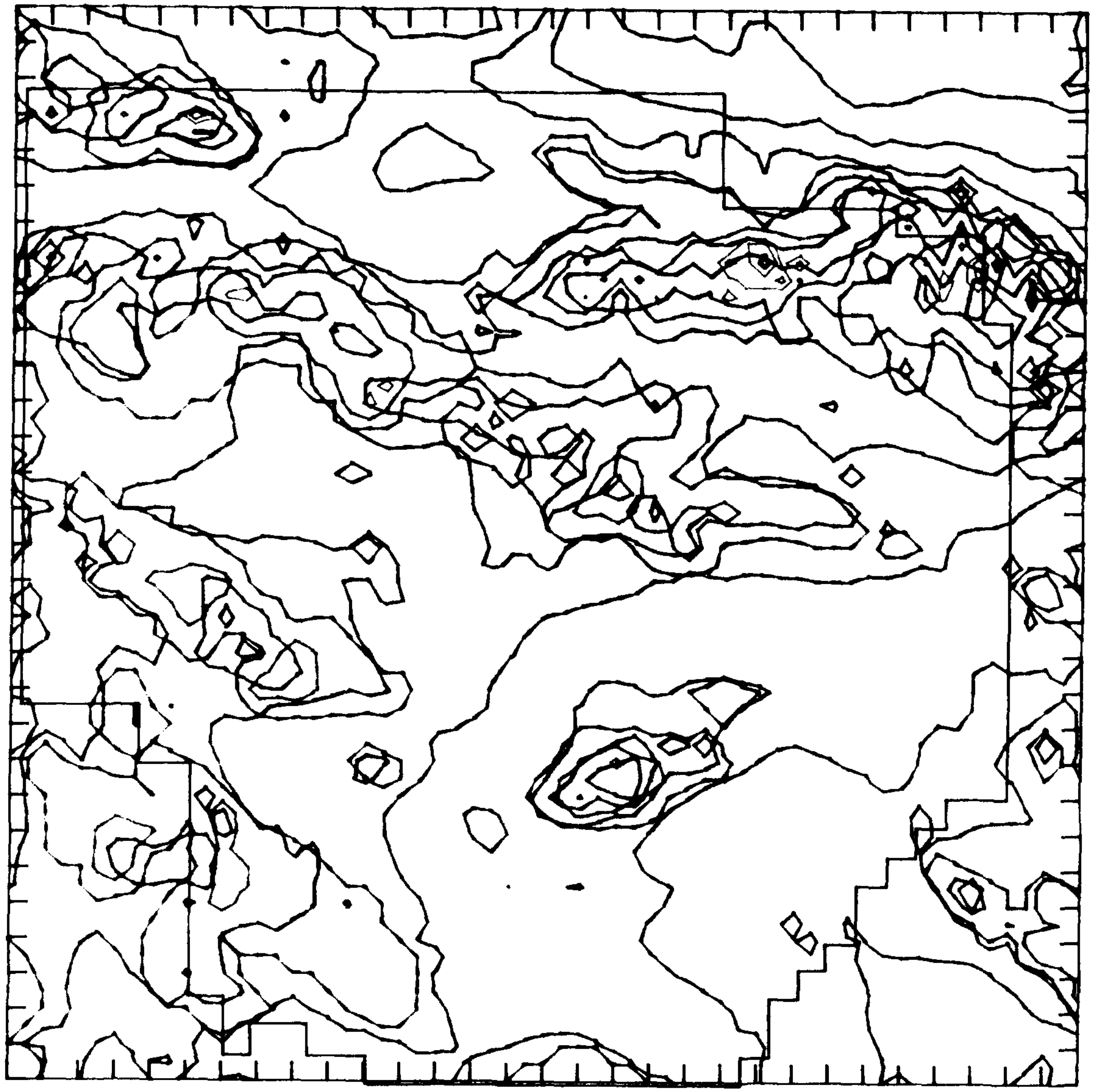
12 May 0000Z

		BYS	901.0	92	94	2
APP (mb)	-1.7	Tower 1	921.4	93	4	3
850 Height (m)	1544	Tower 2	901.0	92	94	2
850 Temp (°C)	23	Tower 3	895.1	88	171	4
850 Wind Dir.	120	Tower 4	884.7	88	283	4
850 Wind Spd (kts)	2	Tower 5	936.1	97	325	5

12 May 1200Z

		BYS	900.3	74	74	4
APP (mb)	-0.3	Tower 1	920.9	75	294	8
850 Height (m)	1530	Tower 2	900.3	74	74	4
850 Temp (°C)	23	Tower 3	894.7	74	11	3
850 Wind Dir.	0	Tower 4	883.8	76	303	6
850 Wind Spd (kts)	0	Tower 5	936.2	77	182	8


** TURBULENCE INDEX **
Terrain Maximum of
Terrain Minimum of
Terrain Contours
Extreme Turb. > 120
Mod. Turb. 70-89
Light Turb. 60-69
29 Feb 1988
1200 GMT



TURBULENCE INDEX

Terrain Maximum of
1766.[illegible] m
at (56[illegible].1, 3931.0)

Terrain Minimum of
62.[illegible] m
at (551.1, 3947.[illegible])

Turb. Index maximum of
131.0[illegible]
at ([illegible]4[illegible].1, 3935.[illegible])

Turb. Index minimum of
[illegible]
at ([illegible]12.1, 3947.[illegible])

Terrain Contours

Extreme Turb. > 120

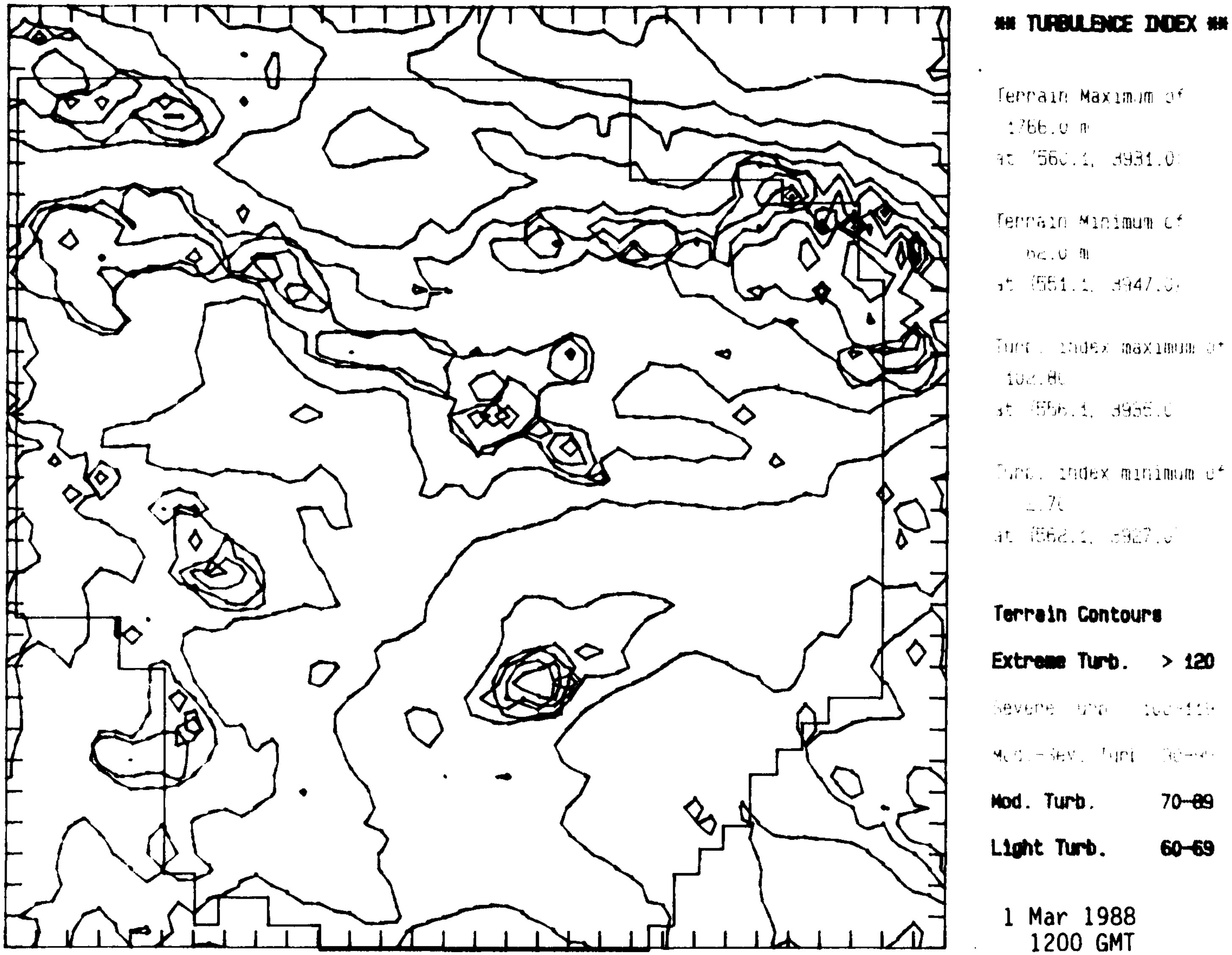
[illegible]

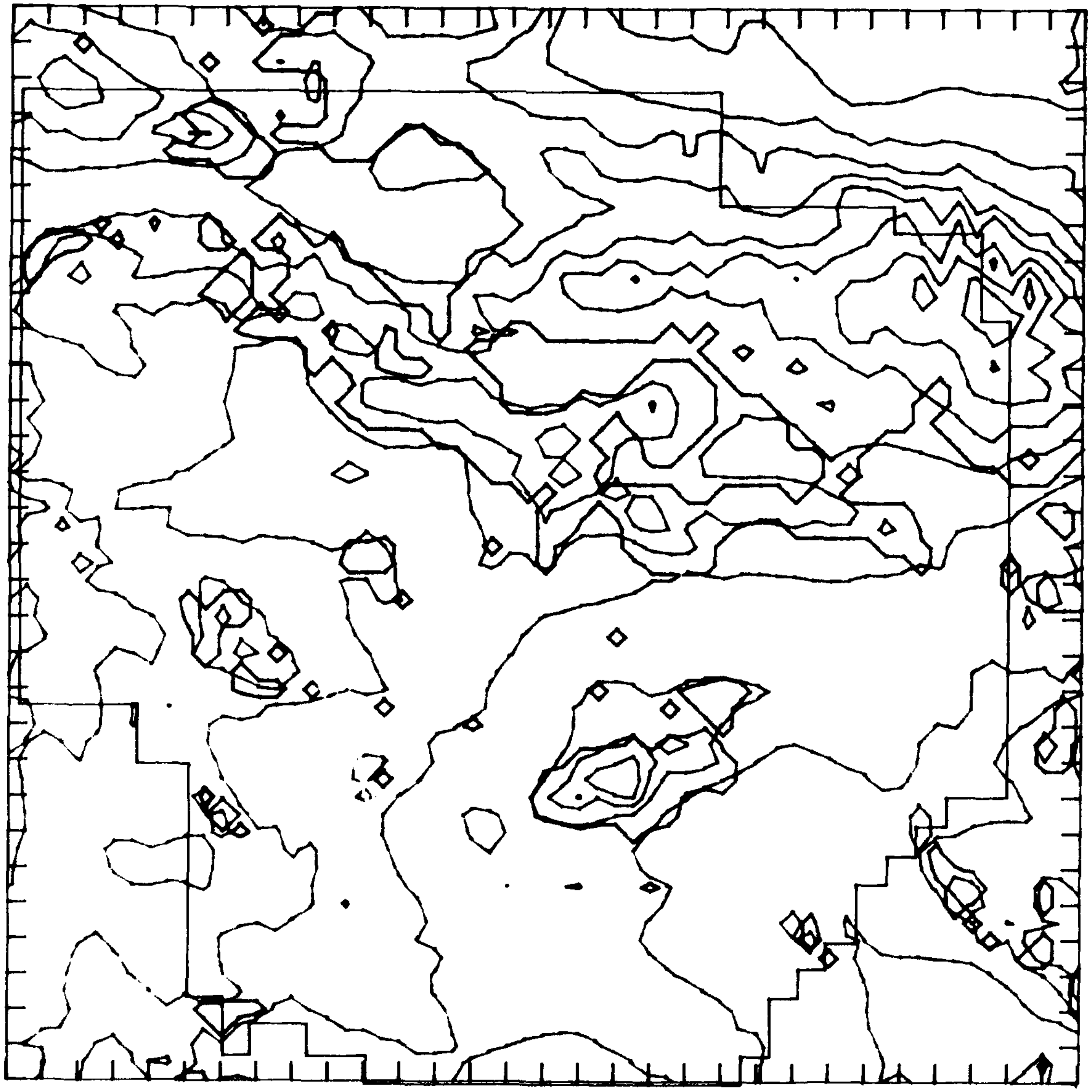
[illegible]

Mod. Turb. 70-89

Light Turb. 60-69

1 Mar 1988
0000 GMT


TURBULENCE INDEX
Terrain Maximum of
1766.0 m
Terrain Minimum of
Terrain Contours
Extreme Turb. > 120
Mod. Turb. 70-89
Light Turb. 60-69
1 Mar 1988
1200 GMT



TURBULENCE INDEX

Terrain Maximum of
1766.0 m
at (560.1, 3931.0)

Terrain Minimum of
62.0 m
at (551.1, 3947.0)

Turb. index maximum of
153.70
at (564.1, 3935.0)

Turb. index minimum of
114.00
at (566.1, 3904.0)

Terrain Contours

Extreme Turb. > 120

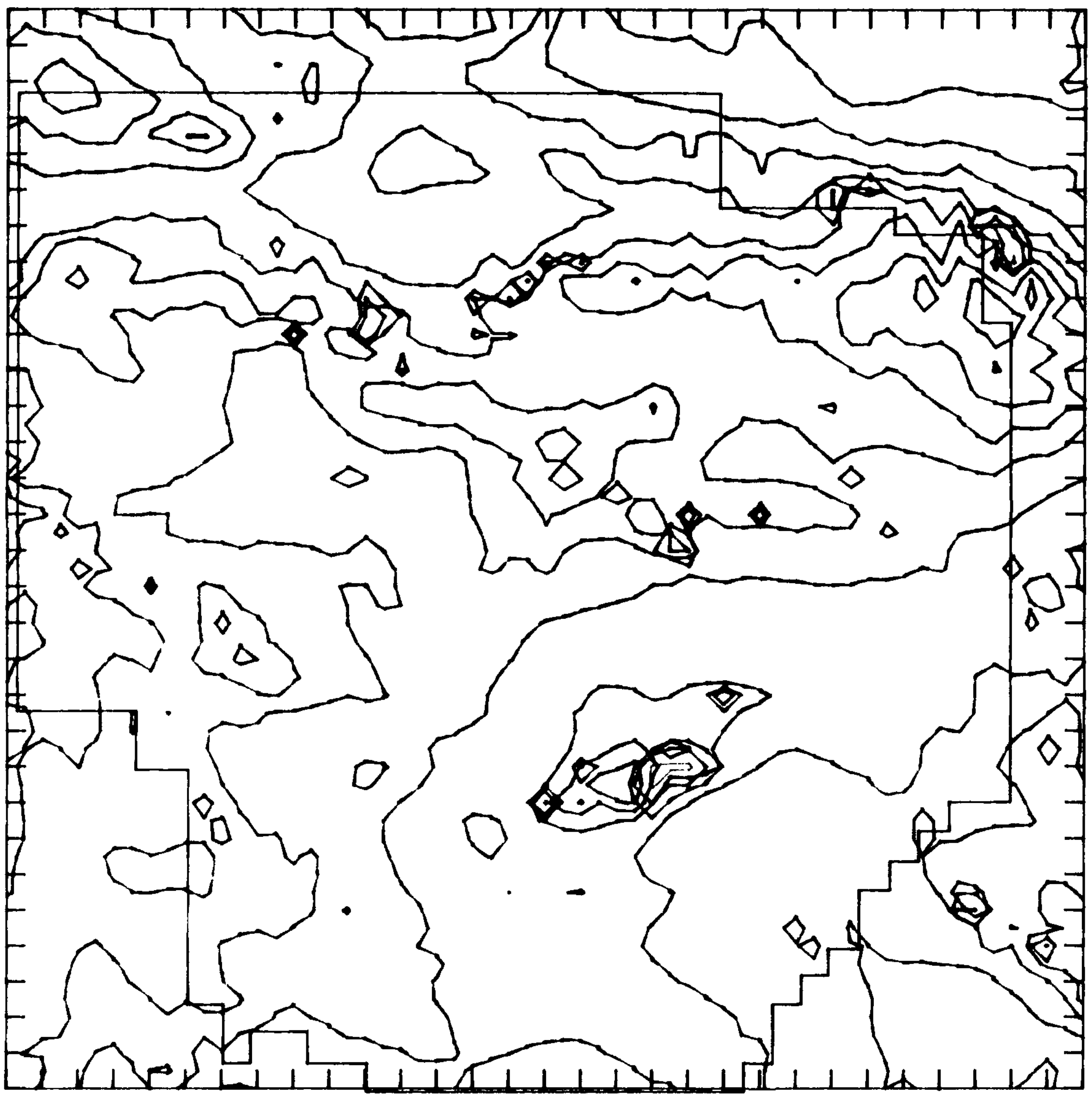
Severe Turb. 100-119

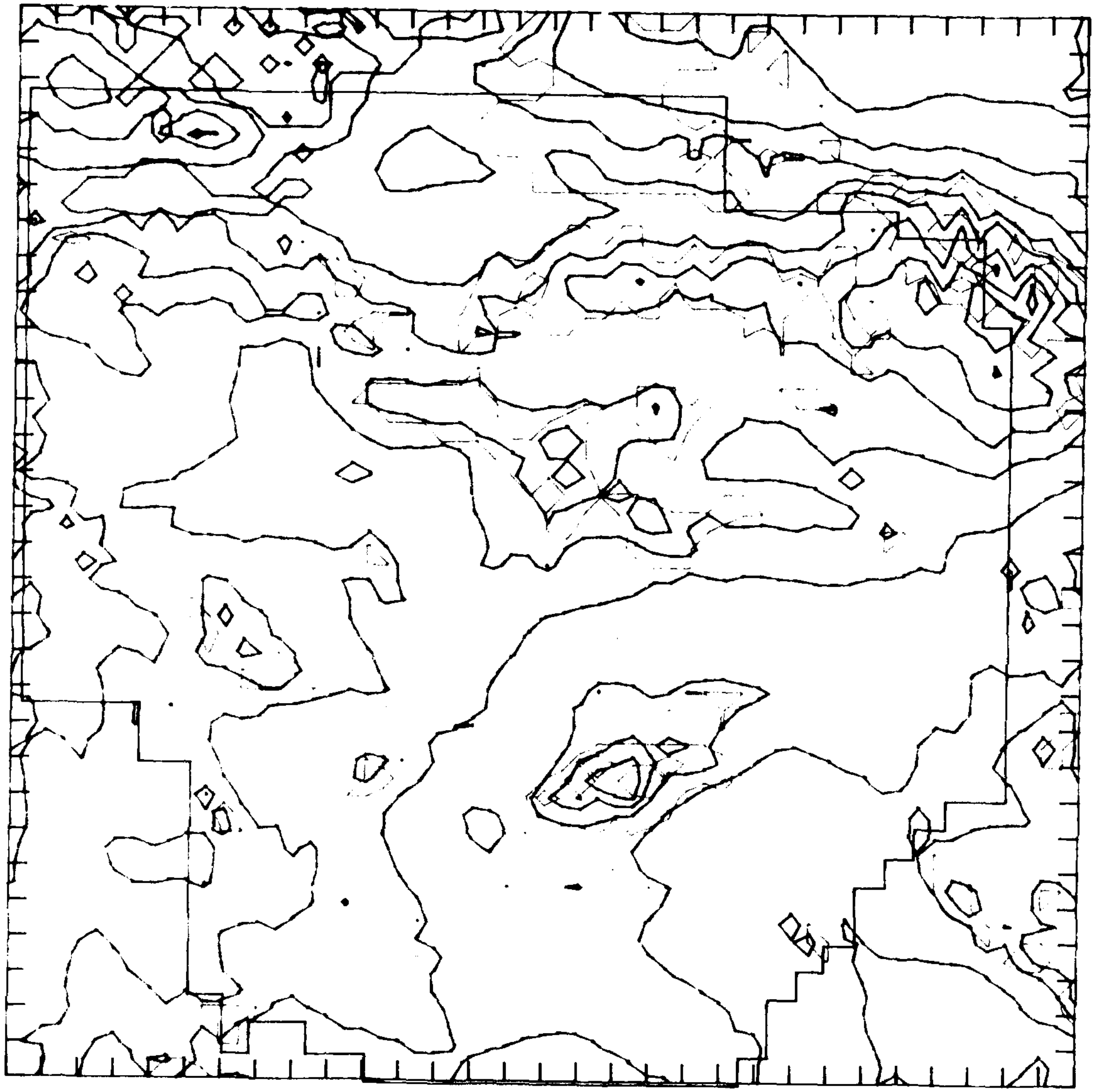
Mod.-Sev. Turb. 90-99

Mod. Turb. 70-89

Light Turb. 60-69

2 Mar 1988
0000 GMT


TURBULENCE INDEX
Terrain Maximum of
1766.0 m
at (560.1, 3951.0)
Terrain Minimum of
at (551.1, 3947.0)
Turb. index maximum of
94.00
at (562.1, 3933.0)
Turb. index minimum of
at (559.1, 3926.0)
Terrain Contours
Extreme Turb. > 120
Mod. Turb. 70-89
Light Turb. 60-69
5 Mar 1988
1200 GMT



TURBULENCE INDEX

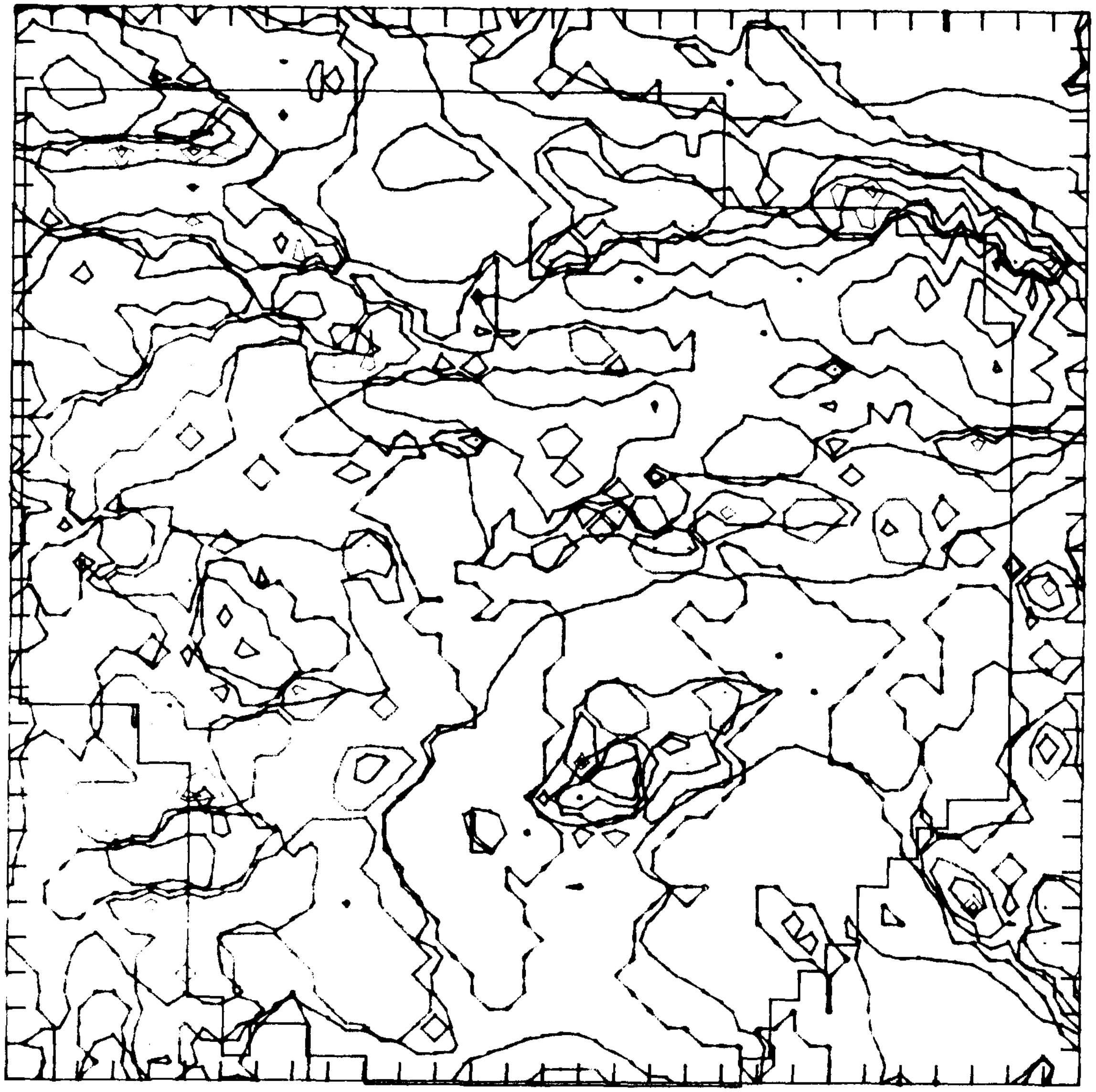
Terrain Contours

Extreme Turb. > .20

Mod. Turb. 70-89

Light Turb. 60-69

6 Mar 1988
0000 GMT



**** TURBULENCE INDEX ****

Terrain Maximum of [illegible]

[illegible]

Terrain Minimum of [illegible]

[illegible]

[illegible] Index Maximum of [illegible]

[illegible]

[illegible] Index Minimum of [illegible]

[illegible]

Terrain Contours

Extreme Turb. > 120

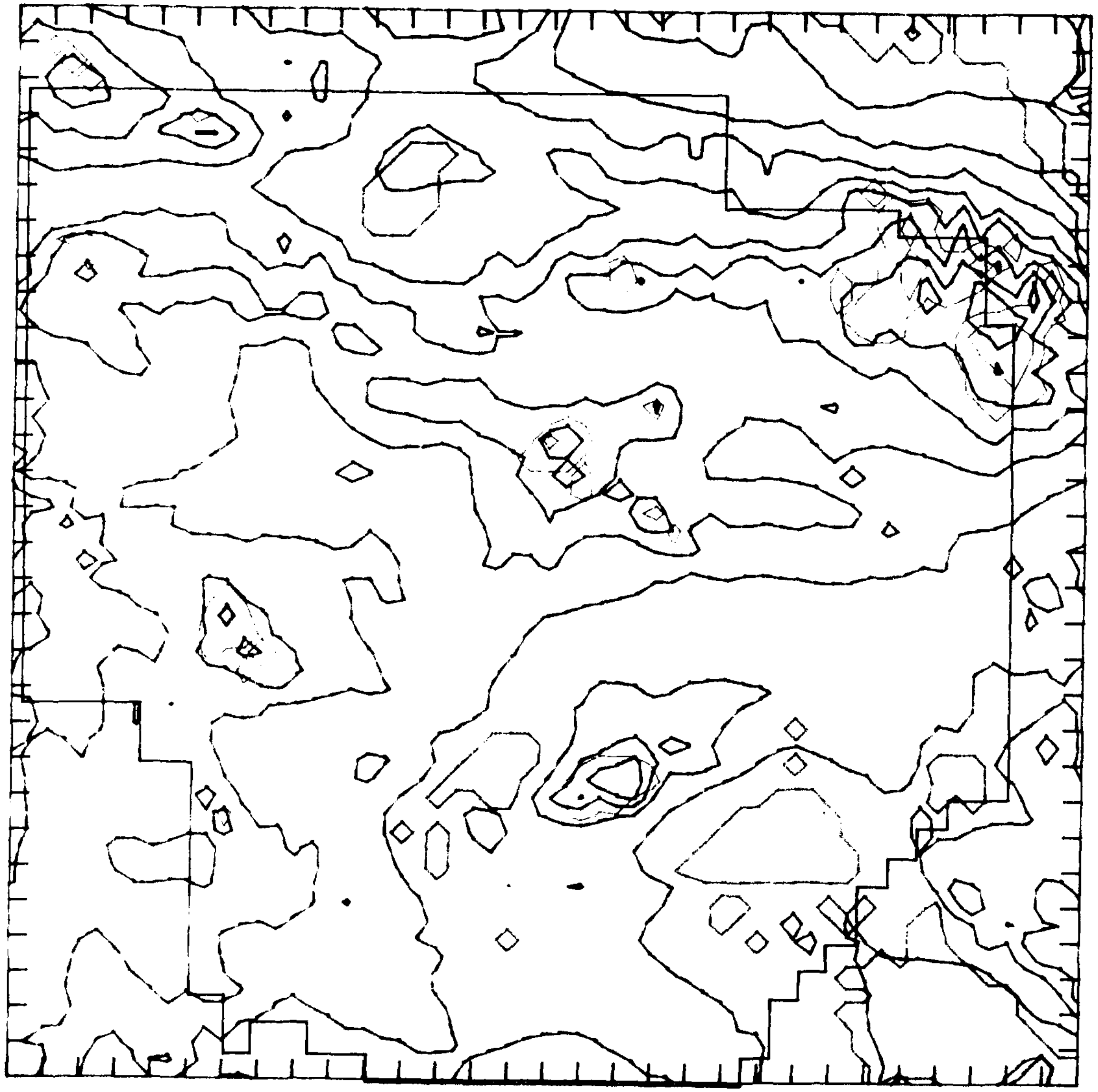
[illegible]

[illegible]

Mod. Turb. 70–89

Light Turb. 60–69

6 Mar 1988
1200 GMT



**** TURBULENCE INDEX ****

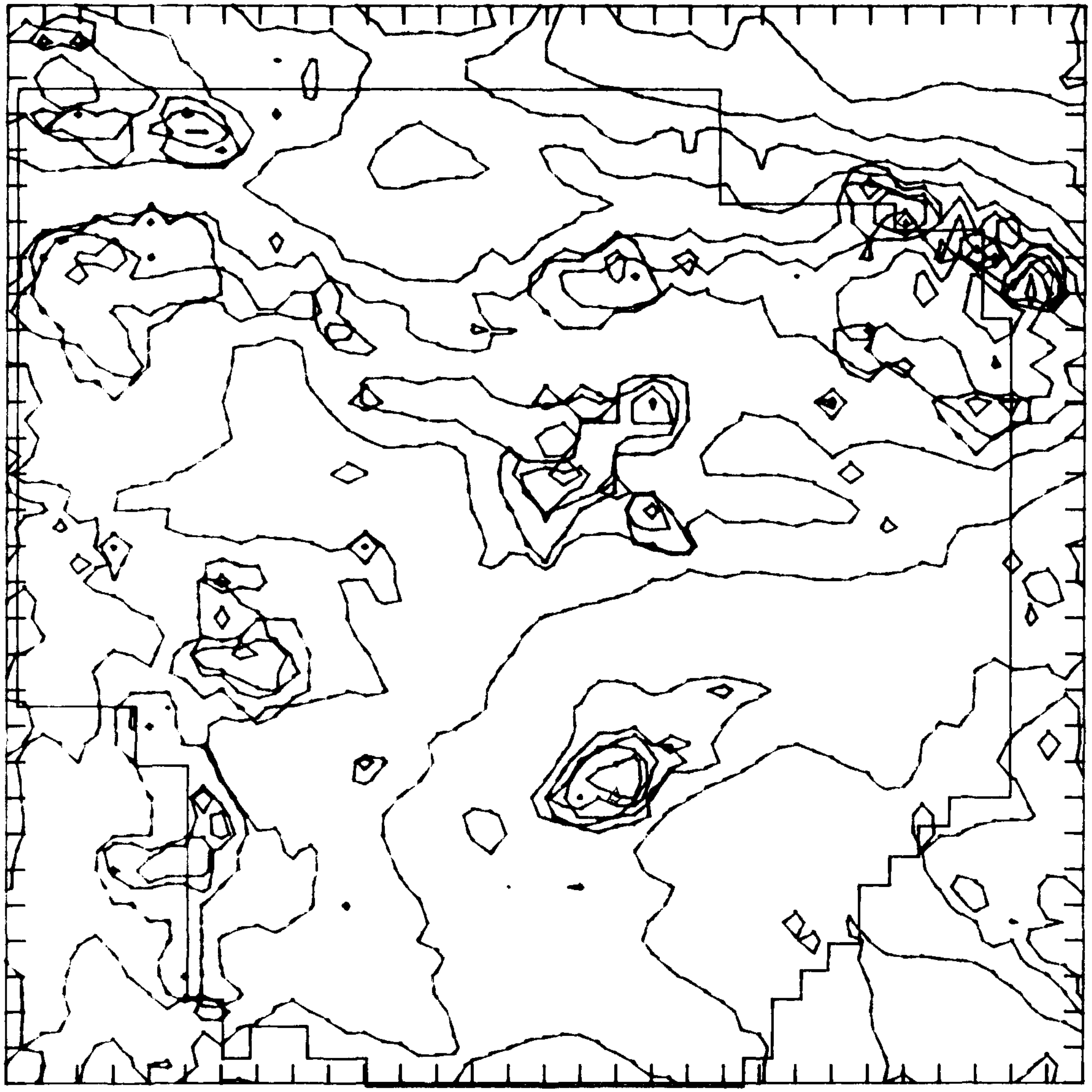
Terrain Contours

Extreme Turb. > **120**

Mod. Turb. 70-89

Light Turb. 60-69

7 Mar 1988
0000 GMT



** TURBULENCE INDEX **

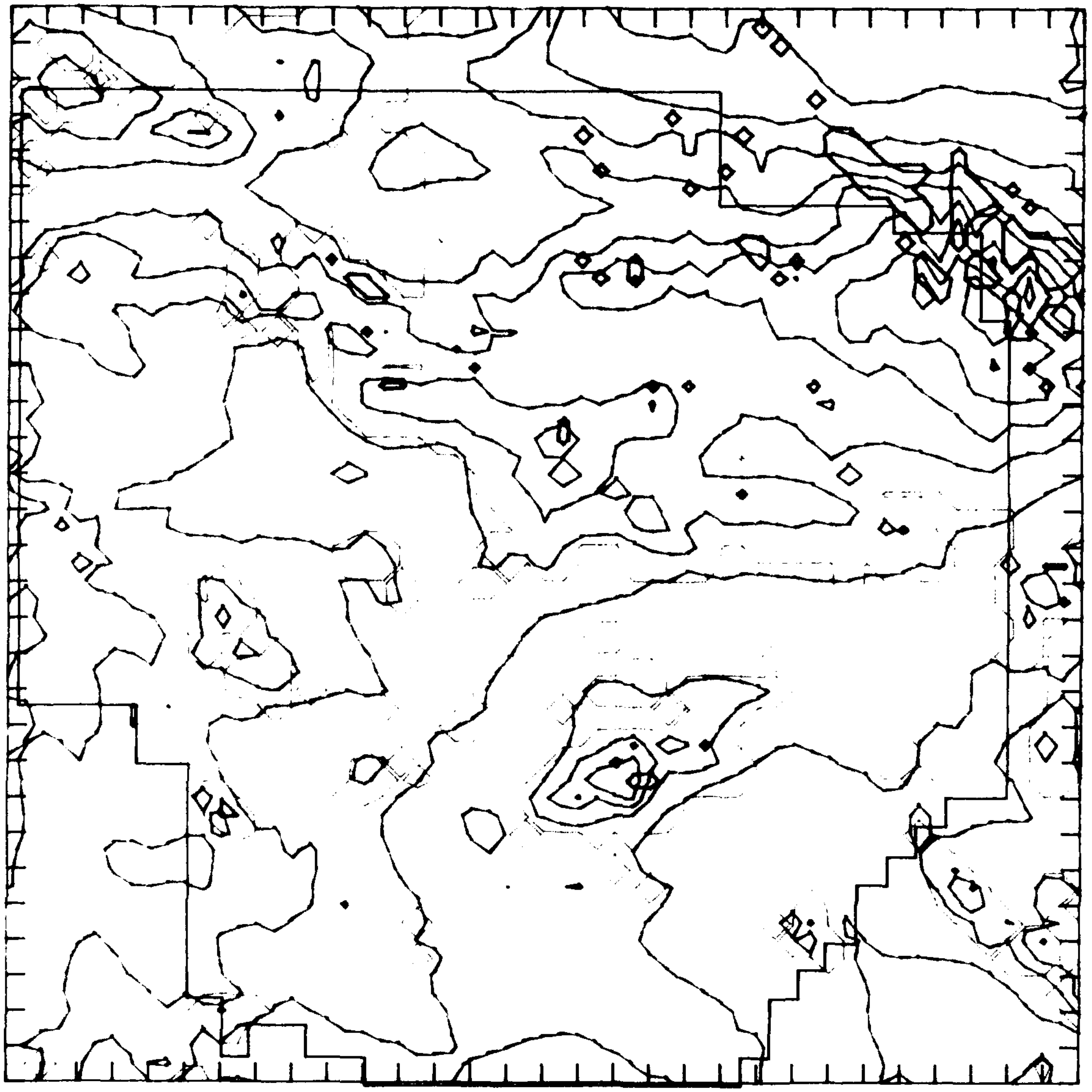
Terrain Contours

Extreme Turb. > 120

Mod. Turb. 70-89

Light Turb. 60-69

22 Apr 1988
1200 GMT



TURBULENCE INDEX

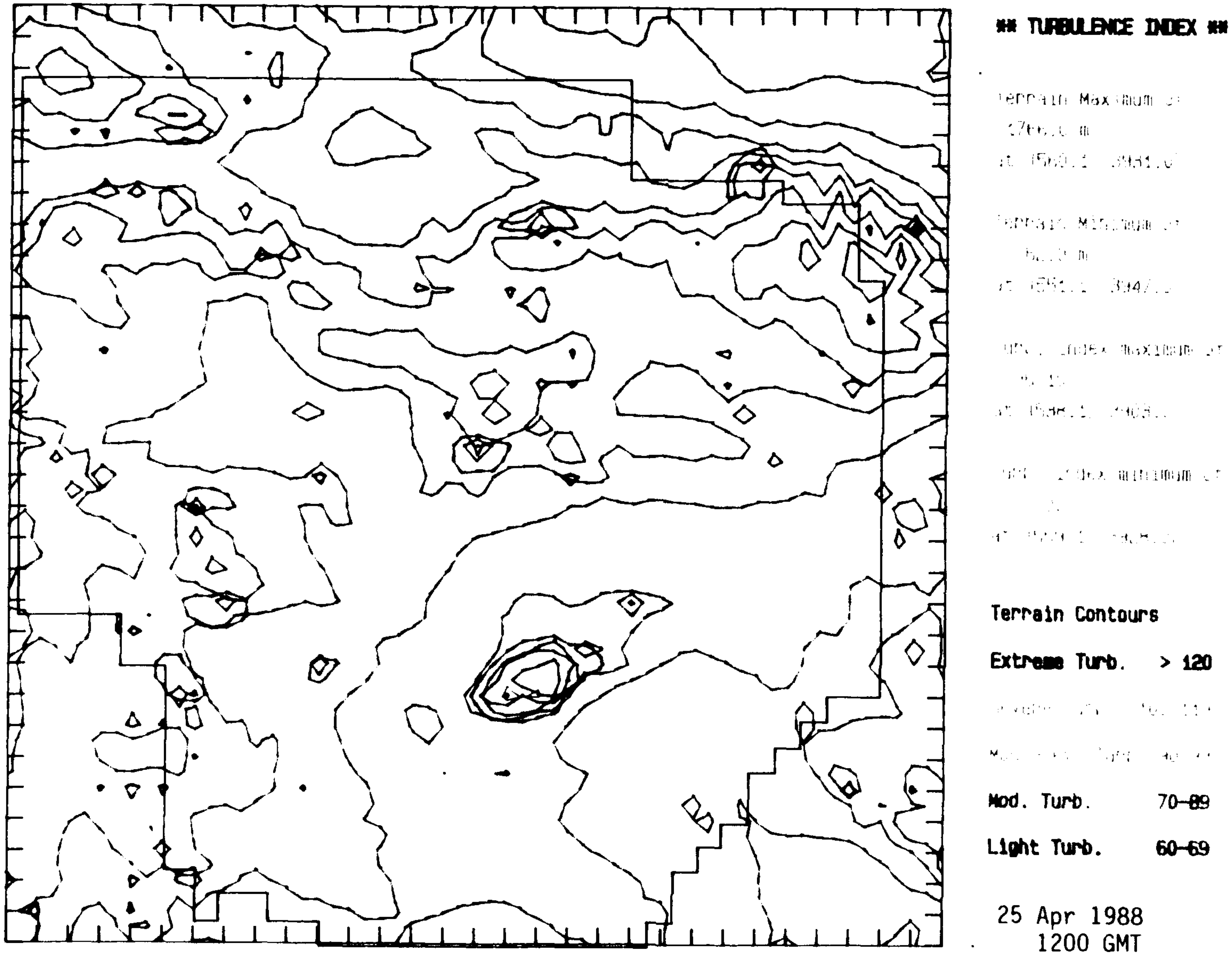
Terrain Contours

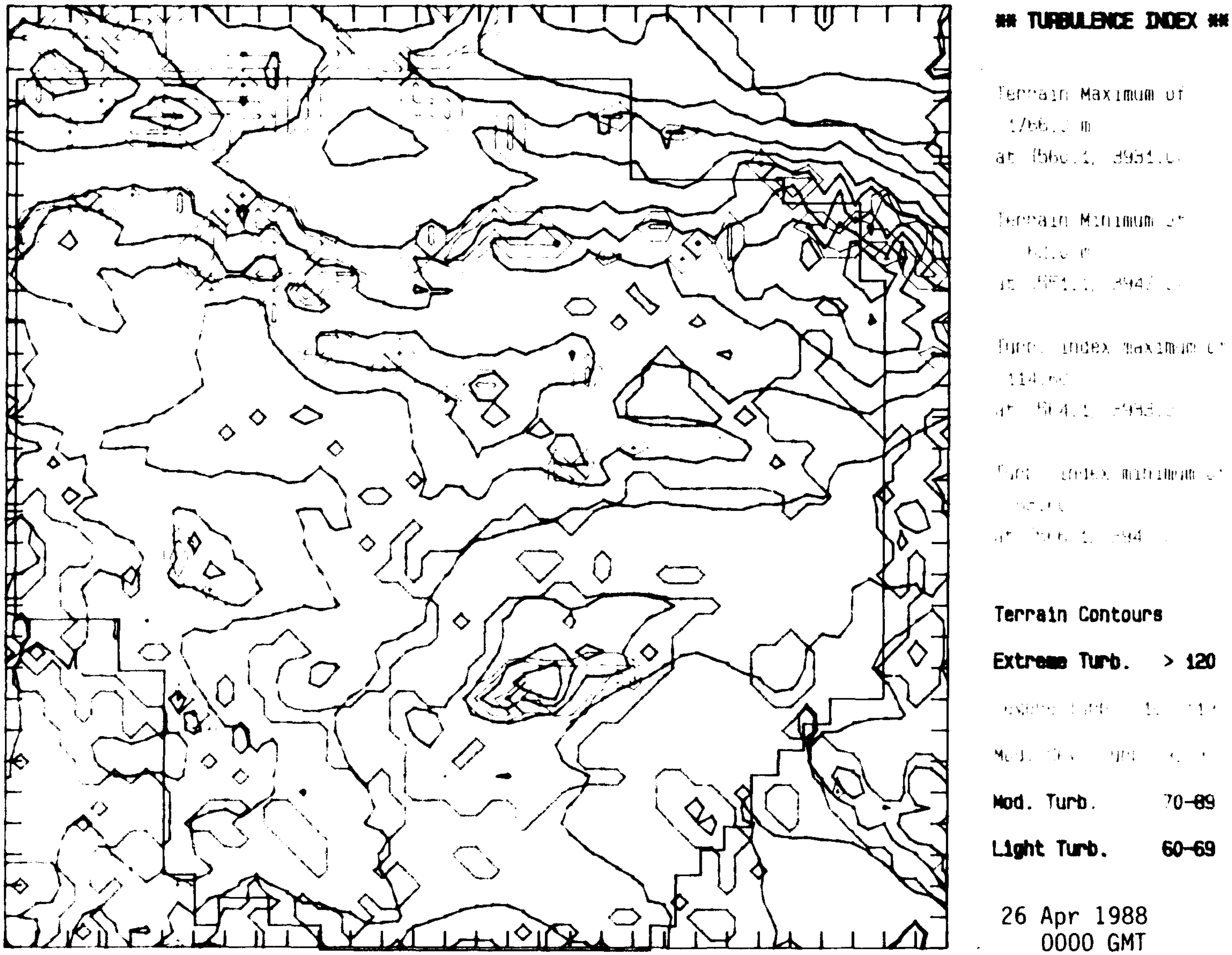
Extreme Turb. > 120

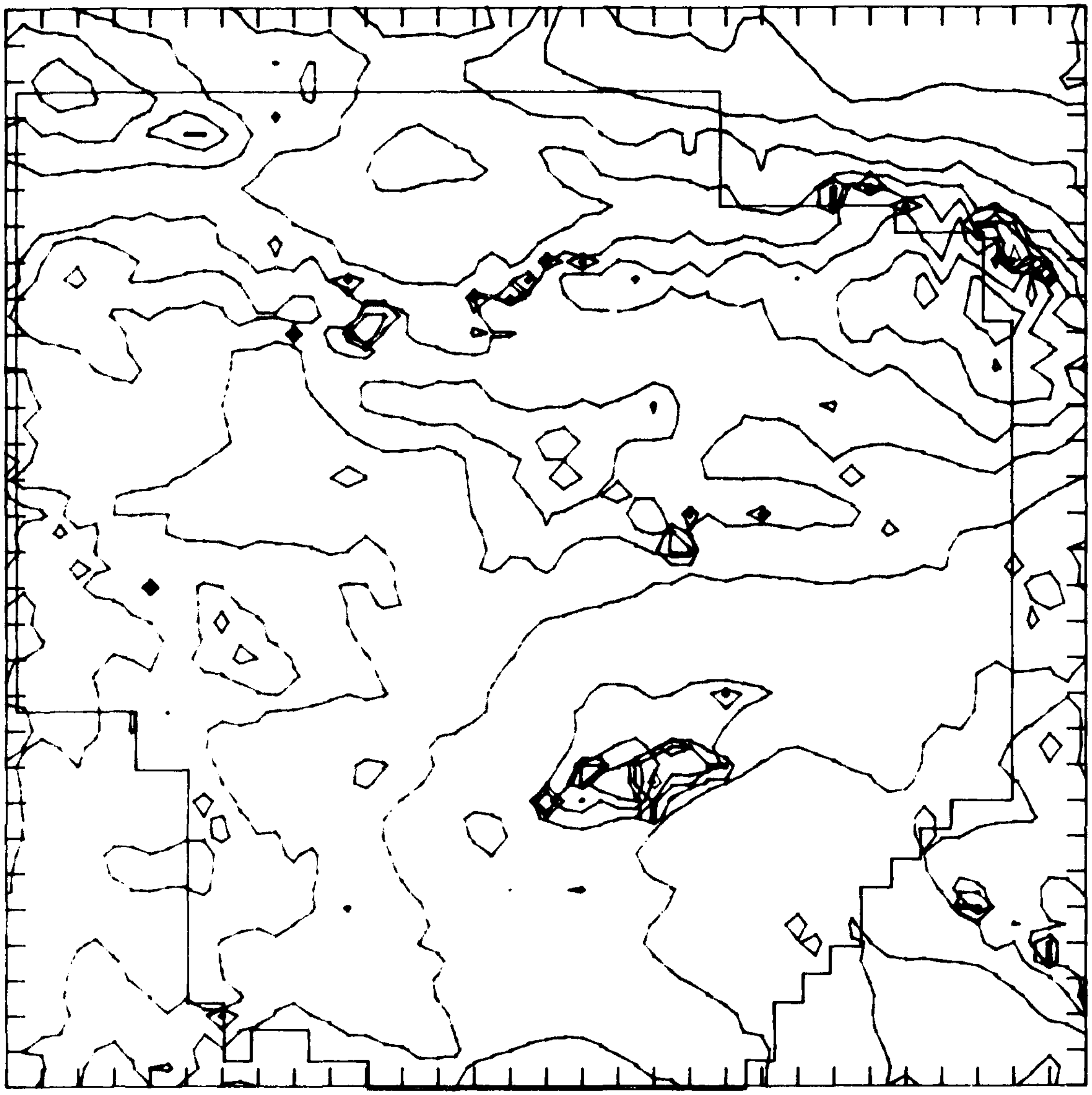
Mod. Turb. 70-89

Light Turb. 60-69

23 Apr 1988
0000 GMT


TURBULENCE INDEX
Terrain Contours
Extreme Turb. > 120
Mod. Turb. 70-89
Light Turb. 60-69
25 Apr 1988
1200 GMT


TURBULENCE INDEX
Terrain Maximum of
Terrain Minimum of
Terrain Contours
Extreme Turb. > 120
Mod. Turb. 70-89
Light Turb. 60-69
26 Apr 1988
0000 GMT



** TURBULENCE INDEX **

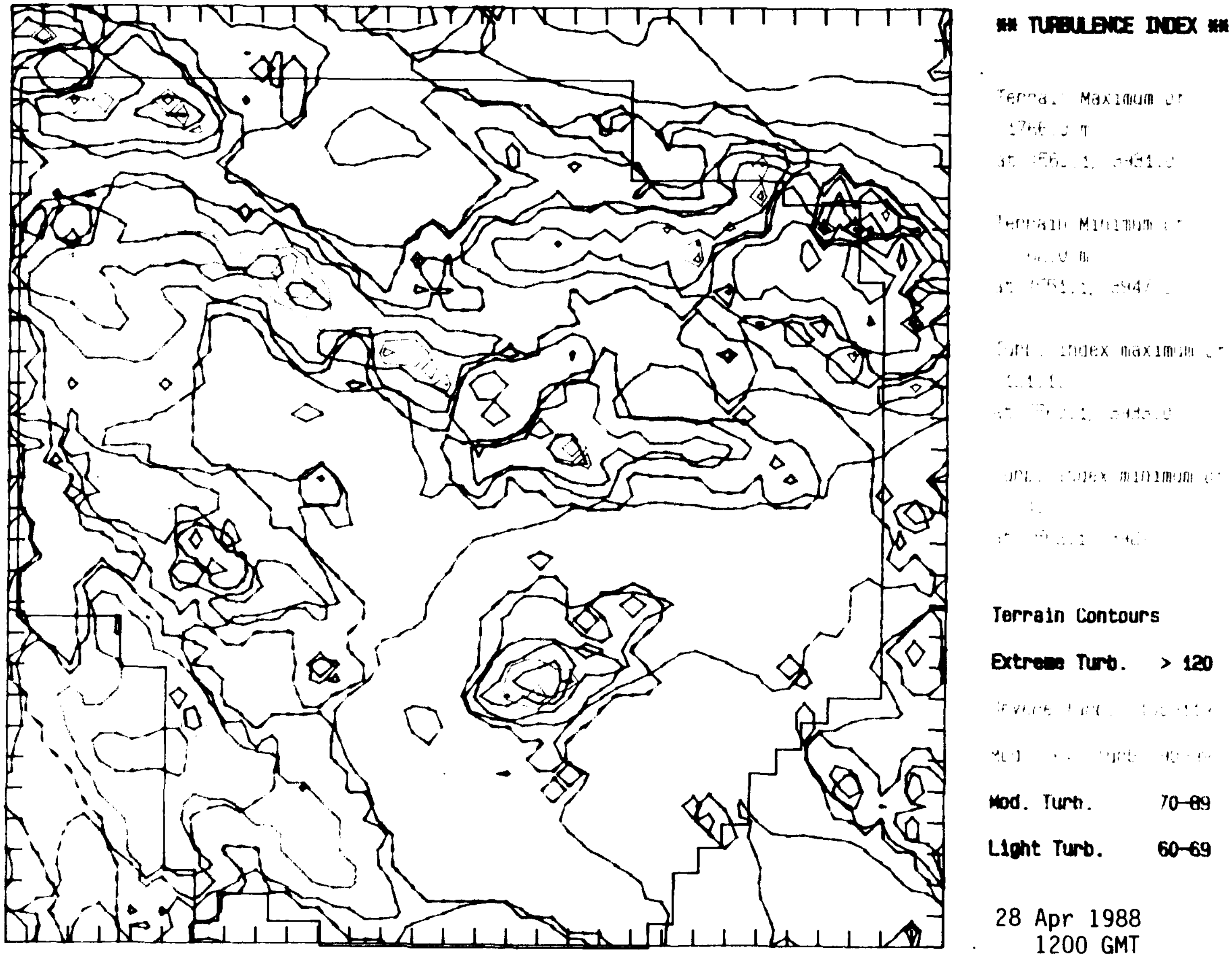
Terrain Contours

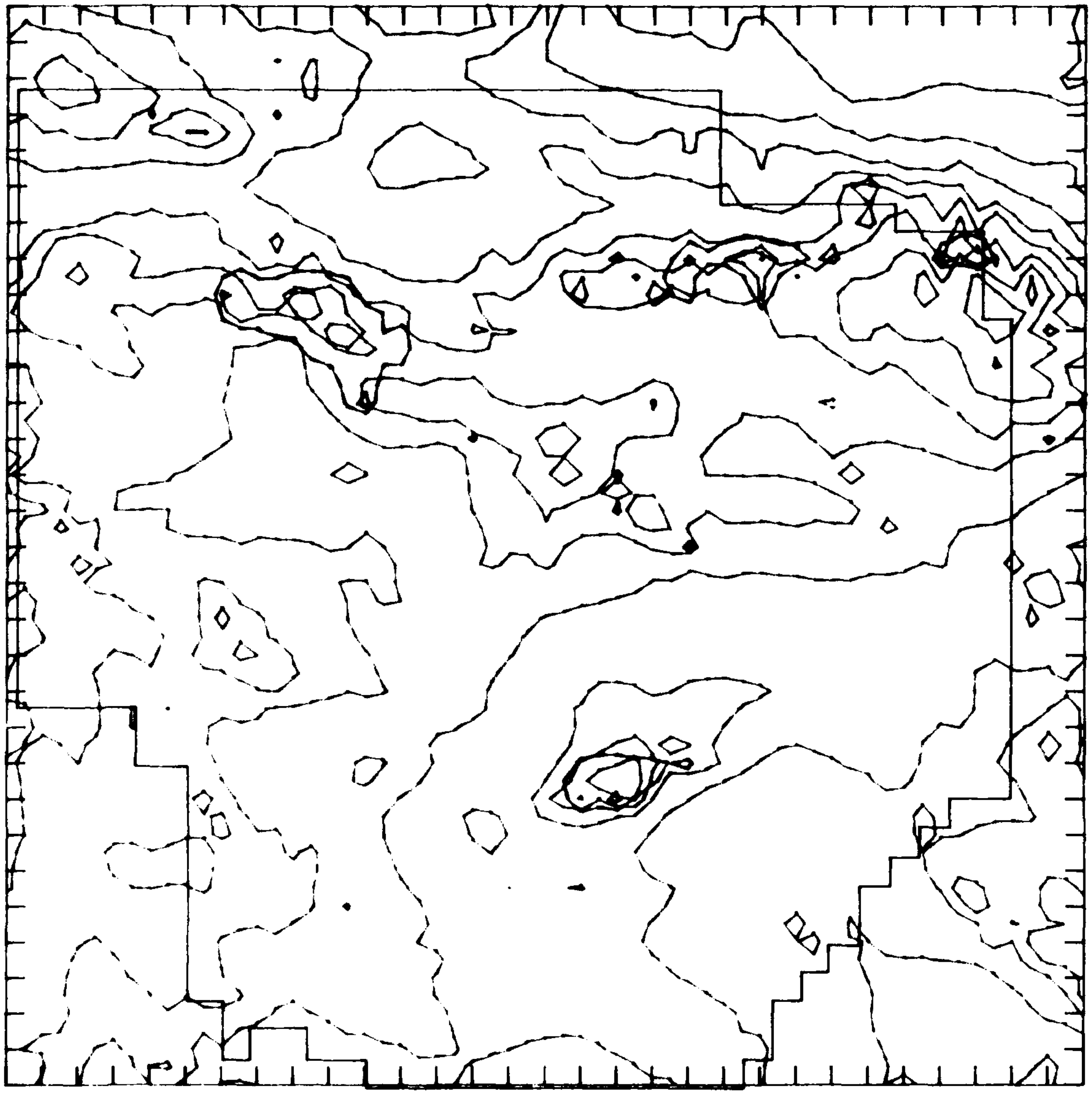
Extreme Turb. > 120

Mod. Turb. 70-89

Light Turb. 60-69

26 Apr 1988
1200 GMT


TURBULENCE INDEX
Terrain Maximum of
Terrain Minimum of
Index maximum of
Index minimum of
Terrain Contours
Extreme Turb. > 120
Mod. Turb. 70-89
Light Turb. 60-69
28 Apr 1988
1200 GMT



TURBULENCE INDEX

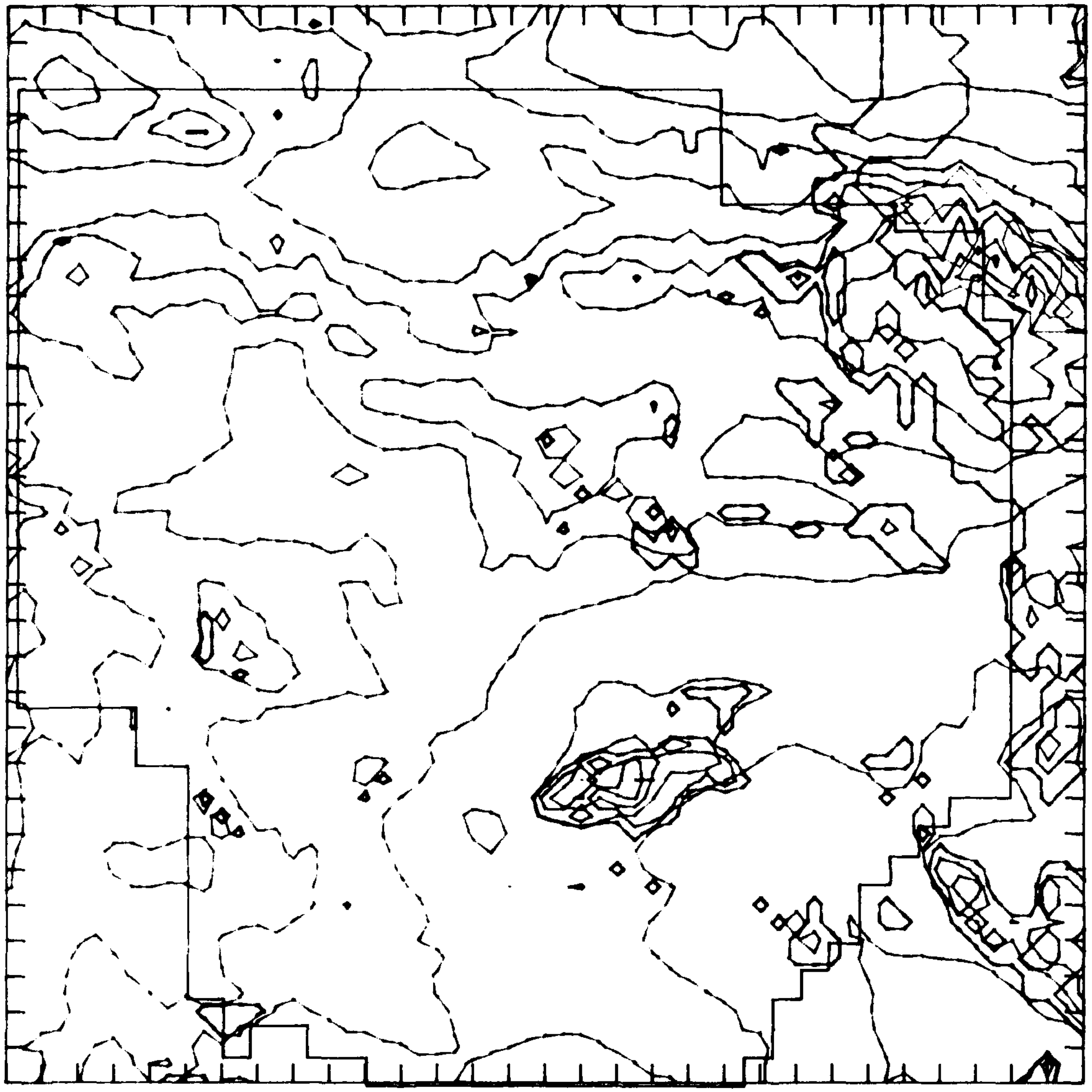
Terrain Contours

Extreme Turb. > 120

Mod. Turb. 70–89

Light Turb. 60–69

10 May 1988
1200 GMT



** TURBULENCE INDEX **

Terrain Maximum of

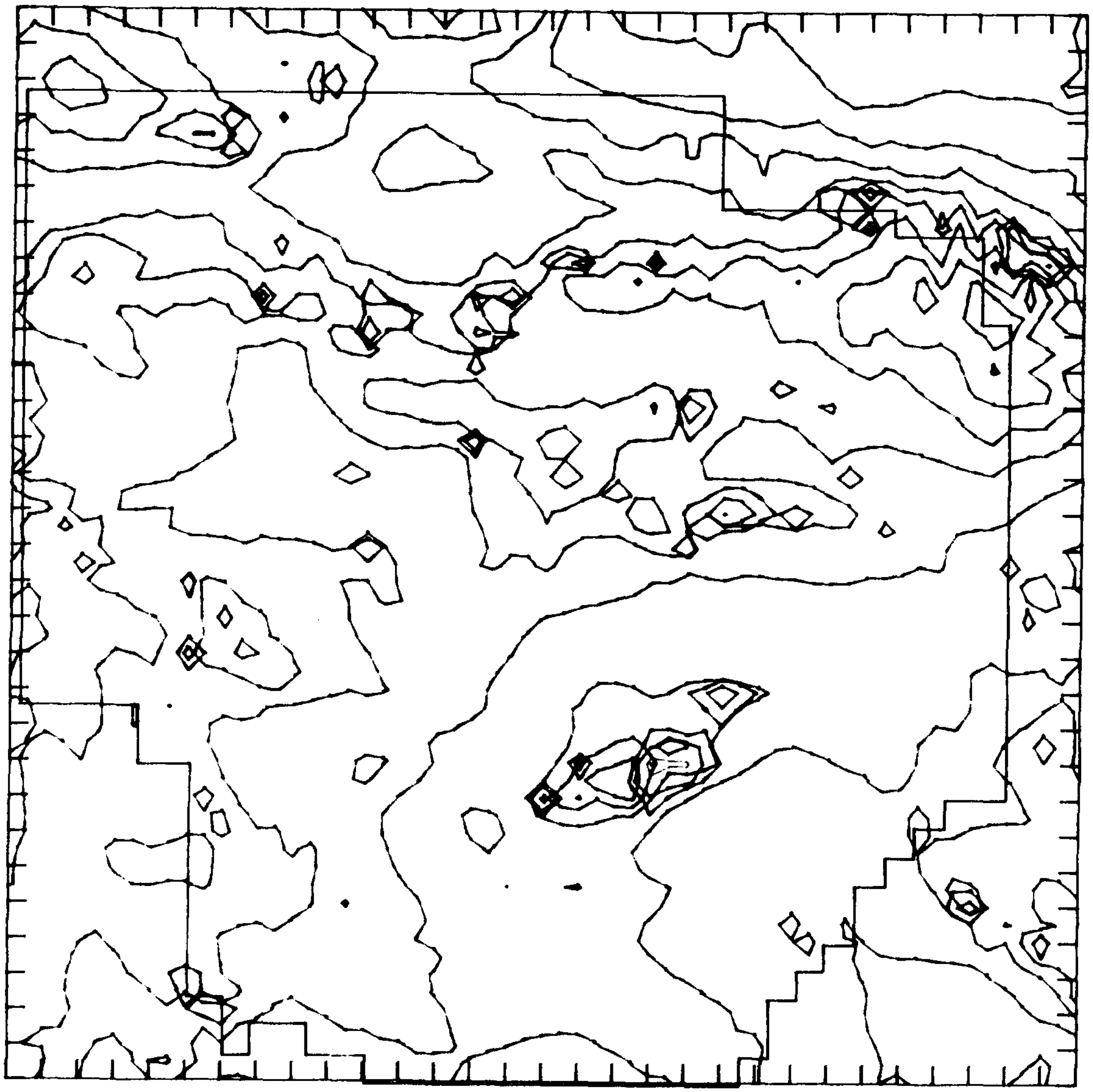
Terrain Contours

Extreme Turb. > 120

Mod. Turb. 70-89

Light Turb. 60-69

11 May 1988
0000 GMT



\#\# TURBULENCE INDEX \#\#

Terrain Maximum of
[illegible] m
at [illegible]

Terrain Minimum of
[illegible]
at [illegible]

Turb. Index maximum of
[illegible]
at [illegible]

Turb. Index minimum of
[illegible]
at [illegible]

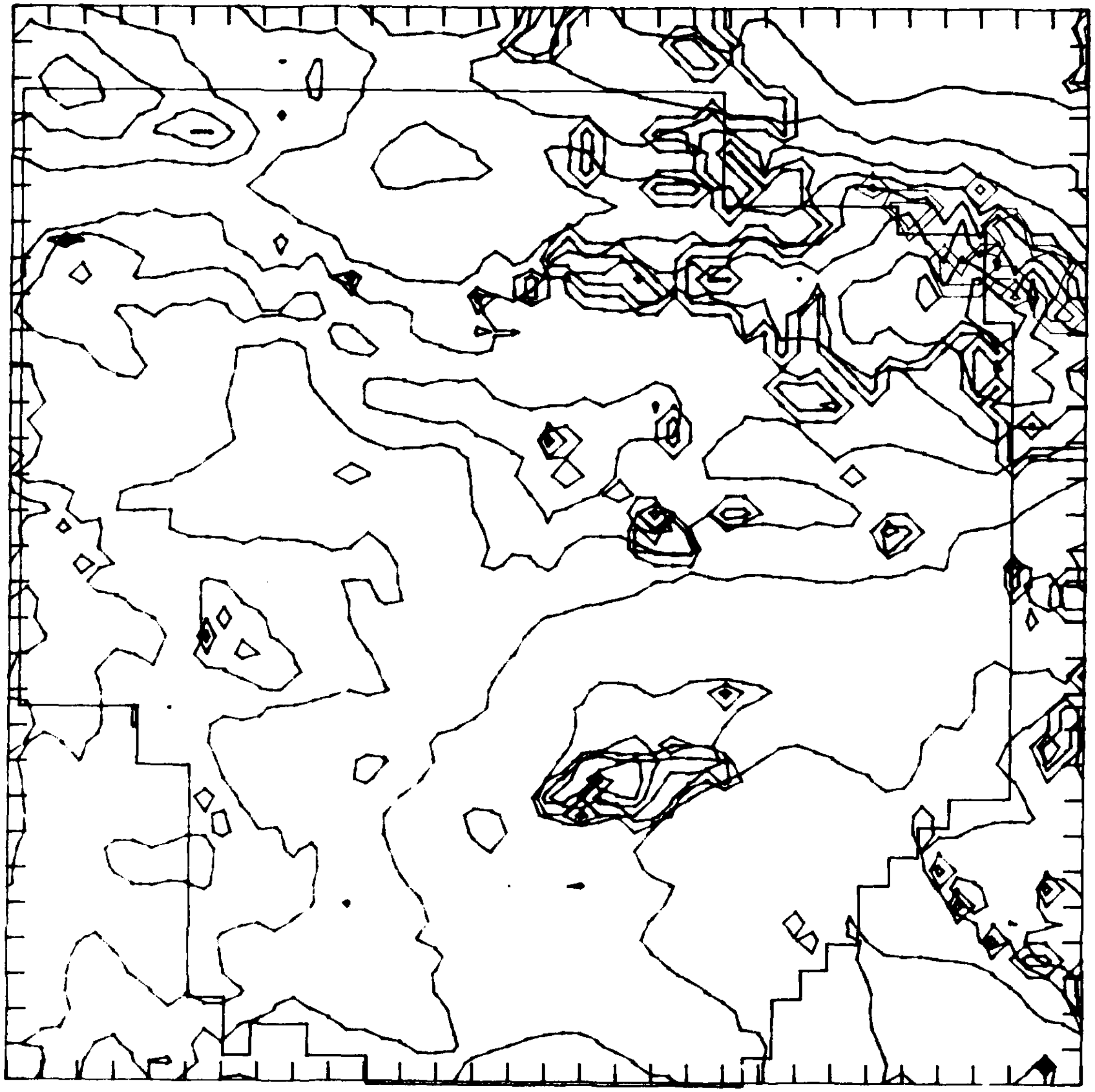
Terrain Contours

Extreme Turb. > 120

Mod. Turb. 70-89

Light Turb. 60-69

11 May 1988
1200 GMT



**** TURBULENCE INDEX ****

Terrain Maximum of
1766.0 m
at (560.1, 3931.0)

Terrain Minimum of
62.0 m
at (551.1, 3947.0)

Turb. index maximum of
118.70
at (564.1, 3933.0)

Turb. index minimum of
14.50
at (518.1, 3920.0)

Terrain Contours

Extreme Turb. > 120

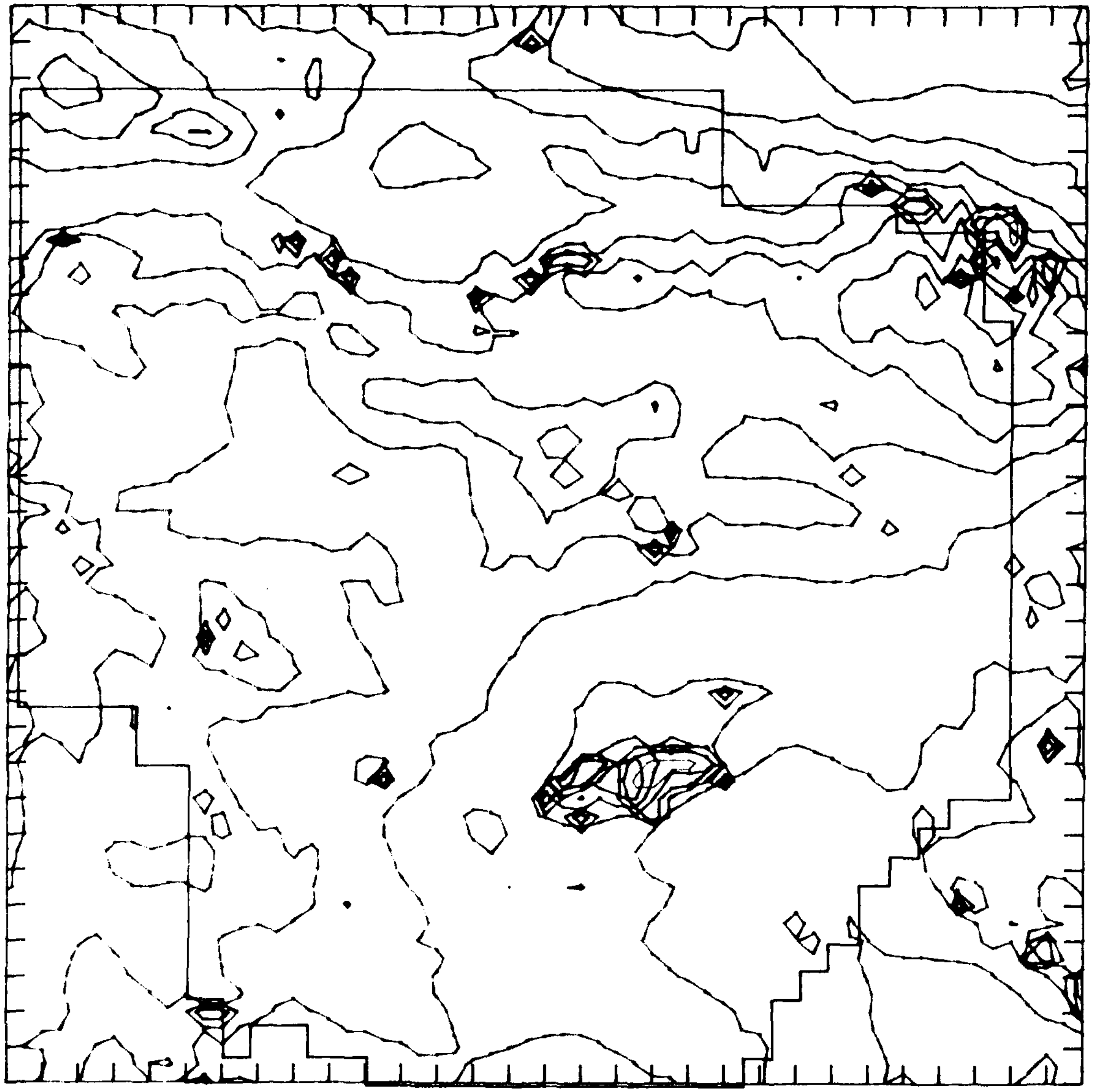
Severe Turb. 100-119

Mod.-Sev. Turb. 90-99

Mod. Turb. 70-89

Light Turb. 60-69

12 May 1988
0000 GMT



** TURBULENCE INDEX **
Terrain Maximum of
1766.0 m
at (560.1, 3931.0)
Terrain Minimum of
62.0 m
at (551.1, 3947.0)
Turb. index maximum of
96.40
at (562.1, 3935.0)
Turb. index minimum of
at (559.1, 3928.0)
Terrain Contours
Extreme Turb. > 120
Severe Turb. 100-119
Mod-Sev Turb 90-99
Mod. Turb. 70-89
Light Turb. 60-69
12 May 1988
1200 GMT

APPENDIX V: Observed vs modelled wind speeds and LTI values.

Values are given for the five meteorological sensor locations at Ft Irwin for case days and times listed. Table V-1 shows observed winds at 5 m compared to 10 m winds output by the WOCSS wind interpolation scheme. In Table V-2, "observed" LTI values are those calculated using the observed winds at 5 m, while "modelled" values indicate LTI values generated by the LTI program.

Table V-1 Observed vs (Modelled) Wind Speed (kts)

	TOWER				
Date/Time (GMT)	1	2	3	4	5
29 FEB/1200	11 (13)	11 (15)	4 (16)	9 (16)	2 (14)
01 MAR/0000	19 (24)	12 (28)	16 (24)	13 (31)	28 (25)
01 MAR/1200	12 (16)	6 (17)	9 (14)	10 (19)	8 (16)
05 MAR/1200	3 (2)	6 (3)	2 (3)	3 (0)	4 (2)
06 MAR/0000	8 (9)	4 (9)	7 (9)	6 (10)	4 (9)
06 MAR/1200	10 (8)	9 (9)	8 (6)	4 (10)	7 (7)
07 MAR/0000	13 (13)	11 (13)	6 (13)	6 (14)	18 (12)
22 APR/1200	17 (12)	8 (12)	6 (11)	7 (14)	20 (11)
23 APR/0000	27 (36)	17 (36)	14 (38)	18 (37)	24 (37)
26 APR/0000	5 (5)	5 (5)	4 (5)	6 (5)	2 (5)
26 APR/1200	3 (2)	2 (2)	4 (2)	2 (0)	3 (2)
28 APR/1200	14 (13)	22 (15)	5 (12)	11 (19)	18 (13)
10 MAY/1200	2 (11)	4 (13)	3 (12)	3 (15)	4 (11)
11 MAY/0000	3 (3)	3 (3)	6 (3)	5 (2)	5 (4)
11 MAY/1200	6 (4)	9 (6)	5 (6)	10 (6)	4 (4)
12 MAY/0000	3 (2)	2 (2)	4 (3)	4 (2)	5 (3)
12 MAY/1200	8 (1)	4 (1)	3 (1)	6 (0)	8 (1)

Table V-2 Observed vs (Modelled) LTI

Date/Time (GMT)	TOWER 1	2	3	4	5
29 FEB/1200	53 (40)	47 (43)	43 (48)	56 (51)	41 (40)
01 MAR/0000	69 (56)	55 (62)	63 (56)	68 (73)	75 (56)
01 MAR/1200	59 (46)	47 (46)	54 (41)	62 (54)	52 (46)
05 MAR/1200	42 (35)	38 (47)	38 (47)	47 (12)	40 (35)
06 MAR/0000	70 (82)	60 (74)	67 (82)	73 (91)	63 (82)
06 MAR/1200	57 (68)	50 (68)	53 (53)	57 (83)	52 (61)
07 MAR/0000	69 (78)	61 (72)	60 (72)	67 (83)	71 (72)
22 APR/1200	63 (52)	48 (48)	49 (44)	58 (60)	63 (48)
23 APR/0000	74 (100)	58 (97)	58 (102)	70 (105)	68 (100)
25 APR/1200	54 (48)	41 (45)	43 (45)	45 (62)	43 (41)
26 APR/0000	65 (76)	59 (64)	62 (76)	71 (89)	59 (76)
26 APR/1200	52 (29)	45 (43)	51 (43)	56 (14)	49 (29)
28 APR/1200	61 (59)	62 (63)	49 (55)	63 (84)	62 (59)
10 MAY/1200	41 (36)	37 (43)	40 (43)	47 (53)	40 (40)
11 MAY/0000	67 (52)	61 (39)	68 (39)	74 (52)	66 (52)
11 MAY/1200	49 (34)	46 (51)	45 (51)	58 (59)	44 (42)
12 MAY/0000	70 (39)	63 (19)	69 (39)	76 (19)	69 (39)
12 MAY/1200	51 (39)	41 (19)	44 (39)	55 (19)	49 (39)